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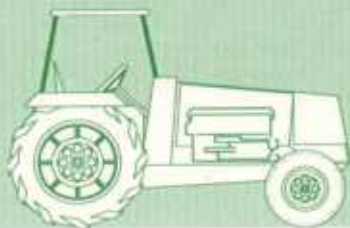
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Pesticide and Fertilizer Use and Trends in U.S. Agriculture

Biing-Hwan Lin
Merritt Padgitt
Len Bull
Herman Delvo
David Shank
Harold Taylor

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Pesticide and Fertilizer Use and Trends in U.S. Agriculture. By Biing-Hwan Lin, Merritt Padgitt, Len Bull, Herman Delvo, David Shank, and Harold Taylor. Natural Resources and Environment Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 717.

Abstract

Pesticides used on major crops more than doubled during 1964-82 (from 233 to 612 million pounds of active ingredients). Nitrogen, phosphate, and potash use for all purposes (agriculture and nonagriculture) rose from 7.5 million pounds in 1960 to a record high of 23.7 million pounds in 1981. These increases in pesticide and fertilizer use were a result of a larger crop acreage, higher application rates per acre, and increased proportions of acres treated with chemicals. Since the early 1980's, pesticide and fertilizer use in U.S. agriculture has declined with crop acreage, and amounted to 574 million pounds of pesticides and 20.7 million tons of fertilizers in 1992. Corn leads other crops, by a substantial margin, in the total quantity of pesticides and fertilizers used. Insecticide use on corn can be greatly reduced by rotating crops and significant reductions in herbicide and nitrogen use can be achieved by adjusting application timing and method.

Keywords: Pesticides, fungicides, herbicides, insecticides, fertilizers, nitrogen, phosphate, potash, production practices

Note

This publication reports research involving pesticides. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

Caution: pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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Summary

Pesticides and fertilizers contribute to increased productivity in agriculture, but their use is also associated with potential human health, wildlife, and environmental risks. Pesticides used on major crops more than doubled during 1964-82 (from 233 to 612 million pounds of active ingredients).

Total expenditures for agricultural chemicals showed a continuous upward trend before peaking in 1982. During this time, fertilizers and pesticides were applied to more acres, and application rates increased. Since 1982, total agricultural chemical usage has varied mainly with changes in planted acreage, government set-aside requirements, and levels of pest infestation.

This report provides information to facilitate policy and regulations related to agrichemicals, and to identify measures that can reduce agrichemical use on corn. The report describes the trend in pesticide and fertilizer use in selected crops from 1964 to 1992. Information is reported for four major pesticide types (herbicides, insecticides, fungicides, and other pesticides). Fertilizers are reported by plant nutrient (nitrogen, phosphate, and potash).

Because recent U.S. Department of Agriculture (USDA) chemical use surveys have not covered all agricultural use, the pesticide use trend is limited to those crops with consistent coverage over time. The included crops (corn, cotton, soybeans, wheat, rice, grain sorghum, peanuts, fall potatoes, other vegetables, citrus, and apples) occupied about 250 million acres (73 percent) of U.S. cropland in the early 1990's and accounted for about 80 percent of total pesticide use in U.S. agriculture during the 1960's. The fertilizer use trend is reported annually for all purposes (agriculture and nonagriculture) and for four crops (corn, cotton, soybeans, and wheat).

Highlights of the report:

- During the 1960's, agricultural pesticide use was dominated by insecticides, accounting for half of all pesticides used. Since 1976, insecticide use has declined, mainly in cotton production, and has accounted for 10 percent of total agricultural pesticide use in recent years.
- During 1964-82, agricultural herbicide use increased more than eightfold, accounting for much of the increase in total pesticide use during the period. Herbicide use accounted for about 70 percent of agricultural pesticide use in recent years. Fungicides and other pesticides (soil fumigants, growth regulators, and harvest aids) accounted for about one-fifth of total pesticides in recent years.
- Nitrogen, phosphate, and potash all shared in the dramatic increase in fertilizer use up to 1981. The relative use of nitrogen, however, increased much more rapidly, from 37 percent of total nutrient use in 1960 to over 50 percent since 1981. This relative gain in nitrogen use has resulted primarily from favorable crop yield responses to nitrogenous fertilizers, especially corn.

- Phosphate's share of total nutrient consumption declined steadily from 34 percent in 1960 to 21 percent in 1992. Potash consumption, historically below that of both nitrogen and phosphate, exceeded phosphate consumption for the first time in 1977 with a share of 26 percent of the total. Use of potash has fallen since 1981, and in 1992, it accounted for 24 percent of total fertilizer use.
- Corn leads other crops, by a substantial margin, in chemical use. In 1992, 79 million acres of cropland were planted with corn (32 percent of crop acres), which received 245 million pounds of pesticides (43 percent of total agricultural pesticides) and 9 million tons of fertilizers (44 percent of total fertilizers for all use). Insecticide use on corn can be greatly reduced by rotating crops, and herbicide and nitrogen use can be significantly reduced by adjusting application timing and method.

Pesticide and Fertilizer Use and Trends in U.S. Agriculture

Biing-Hwan Lin, Merritt Padgitt, Len Bull,
Herman Delvo, David Shank, and Harold Taylor

Introduction

Following World War II, increased agricultural research and education led to the development and adoption of many innovations that changed agriculture. While these changes resulted in tremendous gains in agricultural productivity (USDA/ERS, Apr. 1991),¹ concerns grew about whether the changes were causing environmental damage and posing health risks, and whether the production practices could be sustained to meet the needs of future generations. The increased use of fertilizers and pesticides is a primary focal point for these concerns.

Some pesticides and fertilizers applied to agricultural land potentially move into water supplies and other parts of the environment where they may cause damage or pose health risks. Results from well water surveys and groundwater analyses indicate that agricultural chemicals are detectable in drinking water supplies, sometimes at levels exceeding the U.S. Environmental Protection Agency's (EPA) water quality criteria. EPA's national survey of drinking water wells in 1990 reported 10 percent of the community water systems and 4 percent of the rural domestic wells contained pesticides (USEPA, 1990). EPA also reported that 50 percent of all the wells had detectable levels of nitrates, with 3 percent of the rural domestic wells and 1 percent of the community wells containing nitrate concentration levels above the maximum contaminant level established to protect human health. Other groundwater monitoring studies by universities and private researchers also report frequent detections of pesticide residues (Williams and others; Smith and others, 1987).

Runoff from agricultural land has been identified as a dominant source of surface water pollution. EPA's 1992 National Water Quality Inventory reports that agriculture contributed to 72 percent of the impaired streams and 56 percent of the impaired lakes. Even

though major strides have been made in recent years to reduce surface water pollution from agriculture, surface water pollution continues to dominate water quality issues (Council on Environmental Quality).

High dietary exposure to pesticide residues is suspected to cause a wide range of health problems (National Academy of Sciences (NAS), 1993). However, the quantification of human health risks from exposure to pesticide residues is difficult for several reasons. The validity of making inferences on human health risks from laboratory animal studies is debatable. Reliable data are lacking for actual residue levels on food. The human diet encompasses a wide variety of commodities, resulting in multiple exposure, and the diet changes over time and across the population by age, sex, and ethnic backgrounds. The NAS report points out that infants and children may be at risk of developmental effects from exposure to pesticide residues. Because the potential health risks are uncertain and the scientific knowledge base is weak, pesticide residues are a perceived food safety concern of consumers. For example, the U.S. Department of Agriculture's (USDA) 1990 Diet and Health Knowledge Survey found that over one-half of the Nation's consumers believe that foods grown with pesticides are unsafe (Lynch and Lin).

In addition, farmers, farmworkers, and their families can also be exposed to health risks from pesticides. Such exposure is either through direct contact made when mixing and loading pesticides or through field application activities. EPA currently estimates that there are at least 20,000 illnesses associated with the occupational use of pesticides on farms each year in the United States (USEPA, Aug. 1992).

¹Names in parentheses refer to sources listed in the References before the appendices.

Questions have also been raised about possible ecological changes and long-term sustainability of continued use of high levels of fertilizers and pesticides. The growing incidence of insect and weed resistance to pesticides, increased salinity problems, loss of biodiversity, and the depletion of stock resources used to produce large quantities of plant nutrients or pesticides have raised concerns about the long-term viability of practices which rely on high levels of fertilizers and pesticides.

The Clinton administration has proposed a reduced use/risk policy in response to these rising concerns about health and environmental risks associated with pesticide use. Among other regulatory changes, this policy intends to encourage the use of integrated pest management in agricultural production and to provide incentives for the development of safer pesticides.

In the second section, the aggregate trend in the use of fertilizers and pesticides as well as the aggregate use by major field crops over time are discussed. USDA's surveys of fertilizer (annual) and pesticide (periodic) use are described in appendix A. The assumption and procedures employed to develop the aggregate pesticide use over time are documented in appendix B. The third section presents a disaggregated view of agricultural chemical use by major field crops over time. Specifically, fertilizer use is shown by plant nutrient and by crop (corn, cotton, soybeans, and wheat), and pesticide use is presented by active ingredient and by crop (corn, cotton, potatoes, soybeans, and wheat). Corn is the leading crop in chemical use, and the 1990-92 corn data are analyzed in order to identify and quantify factors that influence chemical use, as shown in section four. Section five summarizes the major findings of the study.

Agricultural Chemical Use Trends

During the late 19th century, prior to the development of chemical pesticides, farmers used inorganic pesticides and a variety of methods to manage yield-reducing effects of weeds, insects, and fungal pests. Common pest management practices included crop rotations, intensive cultivation, sanitation (destruction of crop refuse, removal of diseased plants), trap crops, pruning and defoliation, varying planting dates, and hand removal of weeds and insects (Szmedra). However, these cultural and physical practices could not manage all pests. The search for more effective pest management measures intensified as agriculture became more specialized and new pests became apparent. Research efforts to reduce pest

damages focused on the development of better pest-resistant varieties and chemicals during the 1900-65 period (Smith and others, 1976). The use of synthetic organic pesticides (such as DDT and 2,4-D) in the 1940's created great expectations for satisfactory management of agricultural pests, and provided a cost-effective alternative to the more labor-intensive cultural and physical practices (NAS, 1989).

During the early settlement of the United States, land was plentiful and farmers made little effort to use manure and other waste material produced on the farms as fertilizers. However, growth of east coast cities during the 19th century encouraged the development of recycling waste products for use as fertilizers. During the second half of the 19th century, urbanization created more demands for agricultural products than could be supplied using only recycled waste products as fertilizers. Substitution of Peruvian guano for recycled waste products increased soil fertility and yields. The development of manufacturing capacity to produce superphosphate and other commercial fertilizers eventually replaced most fertilizers produced from recycled wastes (Wines). Later, the capacity to produce anhydrous ammonia and other nitrogen fertilizers provided low-cost nutrients to support the high-yielding potential of newly developed crop varieties and hybrids.

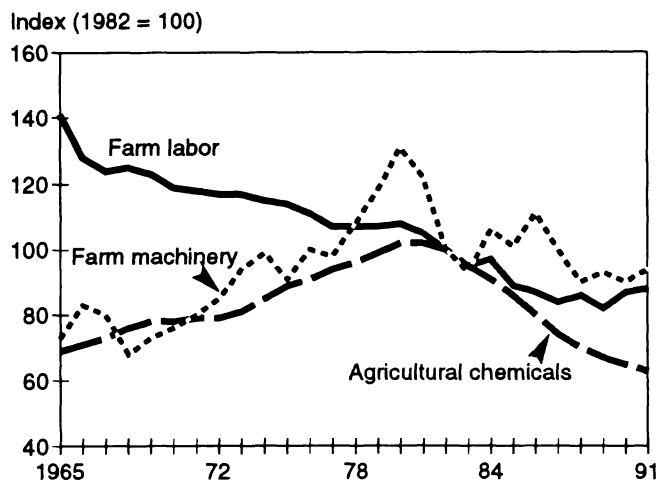
The availability of commercial fertilizers and pesticides encouraged agricultural trends such as increasing farm size and specialization, which in turn increased the dependence on purchased fertilizers and pesticides to meet crop nutrient needs and to manage weeds, insects, and diseases. As illustrated in figure 1, total expenditures for agricultural chemicals showed a continuous upward trend before peaking in 1982. During this time, fertilizers and pesticides were applied to more acres and application rates increased. Since 1982, total agricultural chemical usage has varied mainly with changes in planted acreage, government set-aside requirements, and levels of pest infestation.

In this section, trends in the aggregate use of commercial pesticides and fertilizers in U.S. agriculture are reported. While EPA has published estimates of U.S. pesticide use by sector over time (Aspelin), USDA has conducted periodic surveys to estimate agricultural pesticide use. Agricultural pesticide use during the 1964-82 period has been reported in Osteen and Szmedra, and is updated through 1992 in this report.

Pesticide use is measured in pounds of active ingredients applied to most field crops, vegetables, apples,

Figure 1

Expenditures for agricultural chemicals, machinery, and farm labor



and citrus.² Information is reported for four major pesticide types (herbicides, insecticides, fungicides, and other pesticides). Aggregate fertilizers are reported, by plant nutrient (nitrogen, phosphate, and potash), for total consumption (agricultural and nonagricultural uses), and for four major field crops (corn, cotton, soybeans, and wheat). A brief description of USDA chemical use surveys is presented in appendix A. Appendix B documents the procedure used to construct aggregate pesticide use from periodic pesticide use surveys.

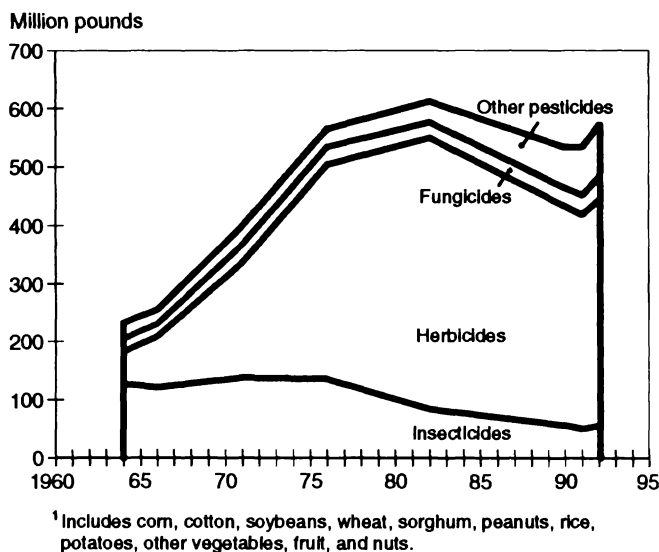
Pesticide Use Trends

The USDA pesticide use surveys provide data for 8 benchmark years (1964, 1966, 1971, 1976, 1982, 1990, 1991, and 1992). Because not all commodities have been surveyed in recent years, we limited the aggregate estimate to those crops with consistent information over time. The major pesticide-using crops include corn, cotton, soybeans, wheat, rice, grain sorghum, peanuts, potatoes, other vegetables, citrus, and apples. Currently, these crops occupy about 250 million acres or about 73 percent of U.S. cropland used for crop production.³ The comprehensive surveys conducted in 1964, 1966, and 1971 reported that these crops accounted for 79-85 percent of total pesticide use in U.S. agriculture. Crops not reported, but which have intensive use of pesticides and significant acreage, include tobacco, sugarbeets, sugarcane, and fruits other than apples and citrus.⁴

Pesticide use on the selected crops grew from 233 million pounds in 1964 to 612 million pounds in 1982 (table 1 and fig. 2). This increase can be attributed to three factors: larger cropland acreage, greater propor-

Figure 2

Pesticide use on selected crops, by pesticide type, 1964-92¹



tion of acres treated with pesticides, and higher application rates per treated acre. Since 1982, annual pesticide use has declined somewhat. After reaching its peak in 1980-82, cropland planted to the selected crops declined and contributed to the reduction in pesticide use.

Dividing the application rate per treated acre by the proportion of acres treated leads to the pesticide application rate per planted acre, which is an indicator of the intensity of pesticide use. The rate increased substantially between 1964 and 1976 when farmers adopted pesticides as a means of managing many problem pests. Since 1976, the rate has remained relatively stable at about 2.2 pounds of active ingredients per planted acre.

²Throughout this report, pesticide use is measured in pounds of active ingredients applied. This measurement may not truly reflect the aggregate human and environmental risks associated with pesticide use, since the risks are also influenced by other factors, such as application timing and method and soil characteristics of the location. Furthermore, the availability of new pesticides which are applied at ultra-low rates may result in a decline in overall pesticide use but not necessarily the overall risks (Torla).

³Recent USDA surveys do not cover pasture, rangeland, and live-stock production. In 1987, there were 36 million acres of cropland used for pasture and 591 million acres of pasture and rangeland. Where data were collected for pesticide use on pasture and rangeland, only 1 to 3 percent of the area was treated with pesticides.

⁴Pesticide use on fruits produced in California was not surveyed in 1991. Because California produces a major share of deciduous fruits (for example, peaches, pears, cherries, plums, and grapes), only apples and citrus are included in this report.

Table 1—Pesticide use on major crops, by pesticide type, 1964-92

Item	1964	1966	1971	1976	1982	1990	1991	1992
<i>1,000 pounds of active ingredients</i>								
Herbicides	54,884	87,351	198,949	368,422	464,596	376,367	368,268	388,175
Insecticides	128,167	121,717	137,808	135,920	84,793	56,621	51,053	57,855
Fungicides	21,715	21,660	30,906	29,546	27,519	31,641	33,112	37,358
Other pesticides	27,983	24,233	31,565	31,072	35,417	68,971	80,893	90,519
Total	232,750	254,961	399,228	564,960	612,325	533,600	533,326	573,907
<i>1,000 planted acres</i>								
Area represented	193,923	194,216	213,930	255,101	275,997	242,220	240,483	248,385
<i>Pounds per planted acres</i>								
Herbicides	0.283	0.450	0.930	1.444	1.683	1.554	1.531	1.563
Insecticides	0.661	0.627	0.644	0.533	0.307	0.234	0.212	0.233
Fungicides	0.112	0.112	0.144	0.116	0.100	0.131	0.138	0.150
Other pesticides	0.144	0.125	0.148	0.122	0.128	0.285	0.336	0.364
Total	1.200	1.313	1.866	2.215	2.219	2.203	2.218	2.311

Note: Numbers may not add to total due to rounding.

Sources: See the references in appendix B, appendix table 1.

During the 1960's, pesticide use was dominated by insecticides, accounting for about half of all pesticides used on the crops considered in this analysis. Since 1976, insecticide use has declined from about 136 million pounds to under 60 million pounds (10 percent of total pesticide use) in recent years. The decrease in insecticide use came mainly from cotton production, where organochlorines (DDT and toxaphene) were banned and replaced by pyrethroids, which are applied at much lower rates. Also, the success of the boll weevil eradication program and adoption of integrated pest management on cotton and other crops contributed to the decrease in insecticide use.

The widespread adoption and use of herbicides, especially on corn and soybeans, accounted for much of the increase in pesticide use during the 1960's and early 1970's. Total herbicide use increased from about 55 million pounds in 1964 to 465 million pounds in 1982, accounting for over three-fourths of total pesticides. Herbicide use then declined to 368-388 million pounds in the early 1990's. The decline in herbicide use coincided with a decline of about 25 million planted acres; average herbicide use per planted acre declined only slightly since 1982.

Fungicides and other pesticides accounted for about one-fifth of all pesticides used on the selected crops.

Because of the lack of comprehensive survey data, the "trend" estimates for fungicides and other pesticides should be interpreted with care. The use of fungicides was most common on peanuts, potatoes, other vegetables, citrus, and apples. About 35 million pounds (94 percent) of total fungicides were applied to these crops in 1992 (table 2). The use of other pesticides (soil fumigants, growth regulators, and harvest aids) was most common in cotton, peanut, potato, and other vegetable production, amounting to 75 million pounds (82 percent) in 1992.

Pesticide Use on Major Crops

Corn occupies the largest acreage of all U.S. crops and far exceeds any other commodity in pesticide use. On a per-acre basis, corn is an intensive pesticide user among field crops, but is less pesticide-intensive than many fruit and vegetable crops. In 1992, 79 million acres of cropland were planted with corn, compared with 4 million acres of vegetables, and 1.4 million acres of citrus and apples. Corn received 245 million pounds of pesticides in 1992, accounting for 43 percent of total pesticides (table 2). Corn acreage accounted for 32 percent of the crop acreage, but used 58 percent of all herbicides and 37 percent of all insecticides. Herbicides accounted for 91 percent of all pesticides applied on corn.

Table 2—Estimated quantity of pesticide active ingredient applied to selected U.S. crops, 1964-92¹

Commodities	1964	1966	1971	1976	1982	1990	1991	1992
<i>1,000 pounds of herbicides</i>								
Corn	25,476	45,970	101,060	207,061	243,409	217,500	210,200	224,403
Cotton	4,628	6,526	19,610	18,312	20,748	21,114	26,032	25,871
Wheat	9,178	8,247	11,622	21,879	19,524	16,641	13,561	17,398
Sorghum	1,966	4,031	11,538	15,719	15,738	13,485	14,156	16,995
Rice	2,559	2,819	7,985	8,507	14,089	16,139	16,092	17,665
Soybeans	4,208	10,409	36,519	81,063	133,240	74,400	69,931	67,529
Peanuts	2,894	2,899	4,374	3,366	4,929	4,070	4,510	3,738
Potatoes	1,296	2,220	2,178	1,765	1,636	2,361	2,547	2,152
Other vegetables	2,195	3,488	3,361	5,419	4,344	4,632	4,496	5,486
Citrus	207	353	546	4,756	6,289	5,639	6,331	6,289
Apples	278	389	156	575	649	386	411	649
Total herbicides	54,884	87,351	198,949	368,422	464,596	376,367	368,268	388,175
<i>1,000 pounds of insecticides</i>								
Corn	15,668	23,629	25,531	31,979	30,102	23,200	23,036	20,870
Cotton	78,022	64,900	73,357	64,139	19,201	13,583	8,159	15,365
Wheat	891	876	1,712	7,236	2,853	970	208	1,153
Sorghum	788	767	5,729	4,604	2,559	1,085	1,140	1,368
Rice	284	312	946	508	565	161	309	178
Soybeans	4,997	3,217	5,621	7,866	11,621	0	445	360
Peanuts	5,518	5,529	5,993	2,439	1,035	1,726	1,913	1,585
Potatoes	1,456	2,972	2,770	3,261	3,775	3,591	3,597	3,514
Other vegetables	8,290	8,163	8,269	5,671	4,465	4,437	4,261	5,141
Citrus	1,425	2,858	3,049	4,604	5,305	3,976	4,145	4,420
Apples	10,828	8,494	4,831	3,613	3,313	3,891	3,841	3,901
Total insecticides	128,167	121,717	137,808	135,920	84,793	56,621	51,053	57,855
<i>1,000 pounds of fungicides</i>								
Corn	0	0	0	20	69	0	0	0
Cotton	171	376	220	49	200	988	701	788
Wheat	0	0	0	862	1,088	172	73	1,155
Sorghum	0	0	0	0	0	0	0	0
Rice	0	0	0	0	80	194	426	388
Soybeans	0	0	0	176	71	0	0	85
Peanuts	1,106	1,108	4,431	6,834	4,740	7,321	8,114	6,725
Potatoes	3,229	3,531	4,124	4,168	4,031	2,808	3,172	3,616
Other vegetables	4,530	4,093	5,667	5,051	6,692	12,173	12,527	16,186
Citrus	4,929	4,056	9,257	5,897	4,881	3,357	3,750	4,000
Apples	7,750	8,496	7,207	6,489	5,667	4,629	4,349	4,416
Total fungicides	21,715	21,660	30,906	29,546	27,519	31,641	33,112	37,358

--Continued

Table 2—Estimated quantity of pesticide active ingredient applied to selected U.S. crops, 1964-92¹
—Continued

Commodities	1964	1966	1971	1976	1982	1990	1991	1992
<i>1,000 pounds of other pesticides</i>								
Corn	76	546	443	483	130	0	0	0
Cotton	12,431	14,207	18,696	12,682	9,347	15,188	15,457	15,841
Wheat	0	47	245	0	0	0	0	0
Sorghum	0	40	0	266	44	0	0	0
Rice	0	0	0	0	17	0	0	109
Soybeans	0	49	52	2,030	2,430	0	0	0
Peanuts	6,990	7,005	471	1,188	1,627	2,364	2,620	2,197
Potatoes	91	10	6,397	8,575	15,188	35,069	45,626	49,671
Other vegetables	5,819	569	3,433	5,060	6,206	16,286	17,174	22,685
Citrus	1,539	681	1,280	214	7	14	15	16
Apples	1,037	1,079	548	574	421	49	0	0
Total other pesticides	27,983	24,233	31,565	31,072	35,417	68,971	80,893	90,519
<i>1,000 pounds of all pesticides</i>								
Corn	41,220	70,145	127,034	239,543	273,710	240,700	233,235	245,272
Cotton	95,252	86,009	111,883	95,182	49,497	50,873	50,349	57,865
Wheat	10,069	9,170	13,579	29,977	23,465	17,782	13,842	19,706
Sorghum	2,754	4,838	17,267	20,589	18,341	14,570	15,296	18,362
Rice	2,843	3,131	8,931	9,015	14,751	16,494	16,827	18,340
Soybeans	9,205	13,675	42,192	91,135	147,362	74,400	70,376	67,974
Peanuts	16,509	16,541	15,268	13,827	12,331	15,482	17,158	14,245
Potatoes	6,072	8,733	15,469	17,769	24,630	43,830	54,942	58,953
Other vegetables	20,834	16,313	20,731	21,201	21,707	37,528	38,459	49,498
Citrus	8,100	7,948	14,132	15,472	16,482	12,986	14,241	14,725
Apples	19,893	18,458	12,742	11,251	10,050	8,955	8,601	8,966
Total all pesticides	232,750	254,961	399,228	564,960	612,325	533,600	533,326	573,907

¹Estimates are for the total U.S. acreage of the selected crops.

Source: See the references in appendix B, appendix table 1, page 40.

Soybeans were the second largest user of pesticides, receiving about 68 million pounds in 1992. Soybeans accounted for about one-fourth of the crop acreage and used about 12 percent of the pesticides. Most soybean acreage received pesticides, but only about 1.1 pounds per planted acre. Nearly all pesticides used on soybeans were herbicides.

Wheat has the second largest acreage, but was the least pesticide-intensive crop; many wheat acres (45 percent) received no pesticide treatments. Wheat accounted for 29 percent of the total acreage, but only about 3.5 percent of the pesticides used in 1992. The 17 million pounds of herbicides applied in 1992 accounted for 88 percent of all pesticides used on wheat.

Cotton, with 13 million planted acres and nearly 58 million pounds of pesticides applied in 1992, accounted for 5 percent of total acreage and about 10 percent of all pesticides applied to the crops included in this analysis. Almost all cotton acreage is treated with pesticides, with an average application rate of over 4 pounds per planted acre. About 45 percent of the pesticides used on cotton were herbicides, 27 percent were insecticides, and 27 percent were other pesticides.

Rice received the most intensive use of herbicides, with 5.6 pounds per planted acre. Herbicides applied to rice accounted for less than 5 percent of total herbicide use, because of its small acreage. Peanuts require intensive fungicide use, accounting for 20 percent of fungicides applied to all crops in 1992.

Vegetables, including potatoes, represented less than 2 percent of the acreage in 1992 but received 19 percent (108 million pounds) of the pesticides. These crops accounted for 15 percent of the insecticides, 53 percent of the fungicides, and 80 percent of other pesticides (soil fumigants, growth regulators, and harvesting aids) used in 1992. In 1992, potatoes received 59 million pounds of pesticides (dominated by other pesticides with 50 million pounds), making potatoes the third largest user of pesticides in terms of poundage.

Like vegetables, citrus and apples received a relatively large share of pesticides. Citrus and apples accounted for less than 1 percent of the total acreage but received 4 percent of the pesticides. The 8 million pounds of fungicides applied to citrus and apples in 1992 accounted for 23 percent of all fungicides.

Fertilizer Use Trends

The USDA Objective Yield Survey has provided annual estimates of primary plant nutrients (fertilizer) use for four major field crops (corn, cotton, soybeans, and wheat) since 1964. While nutrient use on other crops (such as potatoes, rice, sorghum, vegetables, and fruits) has been collected through the Cropping Practices Surveys (CPS) and the Pesticide Data Program (PDP) surveys since 1990, limited information is available for years prior to 1989. Consequently, the aggregate nutrient use trends are based upon *Commercial Fertilizers* (Tennessee Valley Authority; USDA/ERS, 1977-85). The use data are reported on a fertilizer-year basis that begins on July 1 of the previous year and ends on June 30.

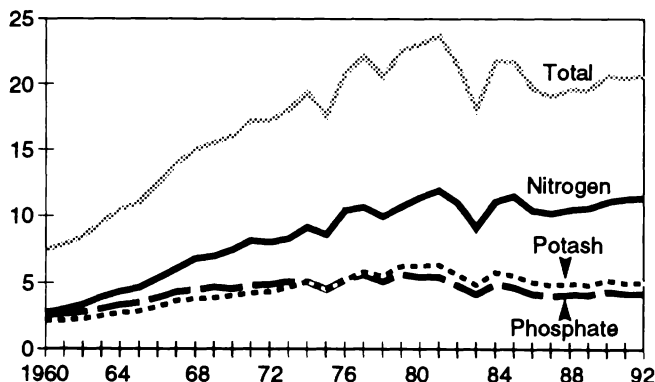
U.S. consumption of nitrogen, phosphate, and potash for all purposes (agricultural and nonagricultural) rose from a total of 7.5 million nutrient tons (tons hereafter) in 1960 to a record high of 23.7 million tons by 1981, an increase of over 217 percent (table 3 and fig. 3). Total nutrient use has fallen somewhat from this level along with total crop acreage, particularly in 1983 as a result of large set-asides associated with the Payment-In-Kind programs, and totaled 20.7 million tons in 1992.

Nitrogen, phosphate, and potash have all contributed to the dramatic increase in nutrient use. The relative use of nitrogen, however, has increased much more rapidly. Nitrogen use stood at 2.7 million tons in 1960, or almost 40 percent of total nutrient consumption. By 1981, nitrogen use had increased by 335 percent to 11.9 million tons, its highest level on re-

Figure 3

Consumption of primary plant nutrients

Million nutrient tons



cord. Nitrogen use stood at 11.4 million tons in 1992, and accounted for 55 percent of total nutrient consumption. This relative gain in nitrogen consumption has resulted primarily from favorable crop yield responses to nitrogenous fertilizers.

While nitrogen's share of total nutrient consumption increased over this period, phosphate's share declined from 35 percent in 1960 to 20 percent by 1992. Phosphate use, which increased by 119 percent from 2.6 million tons in 1960 to a peak of 5.6 million tons in 1977, has basically followed a downward trend since 1979 to 4.2 million tons in 1992.

Potash consumption, historically below that of both nitrogen and phosphate, surpassed phosphate consumption since 1977. Total use of potash increased by 193 percent between 1960 and 1981, from 2.2 to 6.3 million tons during the period. Since then, the consumption of potash has fallen to 5 million tons, paralleling the decline in phosphate consumption. While the shares of total nutrient consumption held by nitrogen and phosphate have increased and decreased, respectively, potash's share has remained stable.

Fertilizer Use on Major Field Crops

U.S. farmers use more primary plant nutrients on corn than on any other crop (table 4 and fig. 4). In 1964, corn acreage received 3.5 million tons of nutrients, or about 34 percent of total U.S. consumption. By 1985, nutrient use on corn more than tripled to 10.6 million tons and accounted for 49 percent of total nutrient consumption. This share stood at 44 percent and amounted to almost 9 million tons in 1992.

Table 3—U.S. consumption of plant nutrients

Year ended June 30	Primary nutrient content ¹				Share of total by nutrient		
	Nitrogen	Phosphate	Potash	Total	Nitrogen	Phosphate	Potash
	----- 1,000 nutrient tons -----				----- Percent -----		
1960	2,738	2,572	2,153	7,464	36.68	34.47	28.85
1961	3,031	2,645	2,169	7,844	38.64	33.72	27.64
1962	3,370	2,807	2,271	8,448	39.89	33.23	26.88
1963	3,929	3,073	2,503	9,505	41.34	32.33	26.34
1964	4,353	3,378	2,730	10,460	41.61	32.29	26.10
1965	4,639	3,512	2,835	10,985	42.22	31.97	25.80
1966	5,326	3,897	3,221	12,445	42.80	31.32	25.88
1967	6,027	4,305	3,642	13,974	43.13	30.81	26.06
1968	6,788	4,453	3,793	15,034	45.15	29.62	25.23
1969	6,958	4,666	3,892	15,515	44.84	30.07	25.08
1970	7,459	4,574	4,036	16,068	46.42	28.46	25.11
1971	8,134	4,803	4,231	17,168	47.38	27.98	24.65
1972	8,022	4,864	4,327	17,213	46.61	28.26	25.14
1973	8,295	5,085	4,649	18,029	46.01	28.21	25.78
1974	9,157	5,099	5,083	19,338	47.35	26.37	26.28
1975	8,601	4,507	4,453	17,561	48.98	25.66	25.36
1976	10,412	5,228	5,210	20,849	49.94	25.07	24.99
1977	10,647	5,630	5,834	22,111	48.15	25.46	26.38
1978	9,965	5,096	5,526	20,587	48.40	24.75	26.84
1979	10,715	5,606	6,245	22,565	47.48	24.84	27.67
1980	11,407	5,432	6,245	23,083	49.42	23.53	27.05
1981	11,924	5,434	6,320	23,678	50.36	22.95	26.69
1982	10,983	4,814	5,631	21,428	51.26	22.47	26.28
1983	9,127	4,138	4,831	18,096	50.44	22.86	26.70
1984	11,092	4,901	5,797	21,790	50.90	22.49	26.60
1985	11,493	4,658	5,553	21,703	52.95	21.46	25.58
1986	10,424	4,178	5,053	19,655	53.04	21.26	25.71
1987	10,210	4,008	4,837	19,054	53.58	21.04	25.38
1988	10,512	4,129	4,973	19,613	53.60	21.05	25.35
1989	10,593	4,117	4,838	19,548	54.19	21.06	24.75
1990	11,076	4,345	5,203	20,624	53.71	21.07	25.23
1991	11,287	4,201	5,001	20,489	55.09	20.50	24.41
1992	11,400	4,210	5,045	20,655	55.19	20.38	24.43

¹Includes Puerto Rico.Sources: Tennessee Valley Authority, *Commercial Fertilizers*, 1984-93; USDA/ERS, *Commercial Fertilizers*, 1977-85.

Among the four field crops surveyed, cotton has the smallest share of total U.S. nutrient consumption and has the smallest amount of acreage. Cotton farmers applied an estimated 778,000 tons of nutrients in 1992, or only 4 percent of total U.S. use. In 1964, however, cotton had the highest per-acre application rate and was second only to corn in total nutrient consumption with an estimated 723,000 tons, or 7 percent of the U.S. total.

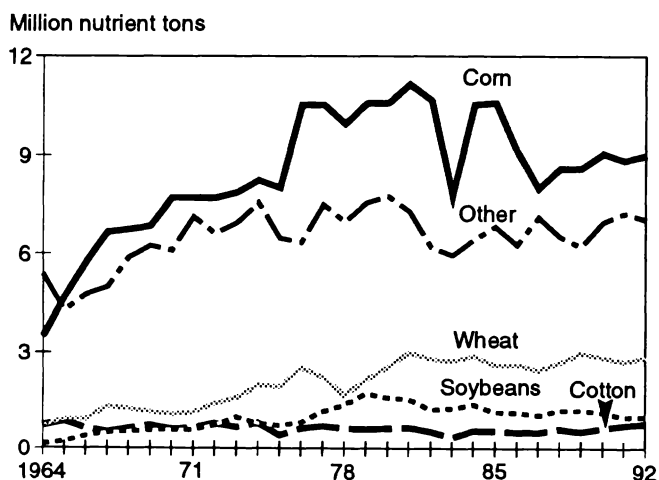
Soybeans received an estimated 143,000 tons of nutrient in 1964, or over 1 percent of total U.S. consumption. Nutrient use on soybeans increased dramatically from this level, and by 1979, reached 1.7 million tons, or 8 percent of total consumption. These changes were due to the combined effects of an increase in the proportion of soybean acreage fertilized, increased application rates, and a 125-percent increase in soybean acreage. Since 1979, however, nutrient use in soybean production has trended downward and by 1992 stood at 1.0 million tons. This decrease in nutri-

Table 4—Total nutrient (nitrogen, phosphate, and potash) used on corn, cotton, soybean, wheat, and other crops, 1964-92

Year	Corn	Cotton	Soybean	Wheat	Other	Total
<i>1,000 nutrient tons</i>						
1964	3,504	723	143	708	5,382	10,460
1965	4,691	860	226	904	4,304	10,985
1966	5,735	633	389	903	4,784	12,445
1967	6,652	518	491	1,310	5,003	13,974
1968	6,748	629	534	1,238	5,883	15,034
1969	6,842	730	551	1,146	6,247	15,515
1970	7,702	603	586	1,077	6,101	16,068
1971	7,701	646	573	1,124	7,125	17,168
1972	7,691	791	728	1,387	6,616	17,213
1973	7,871	670	973	1,584	6,932	18,029
1974	8,239	805	792	1,962	7,544	19,338
1975	8,010	428	723	1,924	6,475	17,561
1976	10,532	634	818	2,512	6,353	20,849
1977	10,539	711	1,153	2,220	7,488	22,111
1978	9,951	625	1,369	1,665	6,977	20,587
1979	10,577	603	1,706	2,127	7,553	22,565
1980	10,584	632	1,581	2,538	7,748	23,083
1981	11,161	657	1,539	3,015	7,306	23,678
1982	10,657	531	1,213	2,817	6,210	21,428
1983	7,780	359	1,260	2,733	5,965	18,096
1984	10,541	566	1,363	2,894	6,426	21,790
1985	10,588	542	1,142	2,598	6,832	21,703
1986	9,103	518	1,123	2,632	6,280	19,655
1987	7,980	502	1,040	2,421	7,111	19,054
1988	8,600	611	1,191	2,670	6,521	19,613
1989	8,595	535	1,205	2,992	6,220	19,548
1990	9,039	643	1,123	2,846	6,974	20,624
1991	8,829	727	998	2,714	7,221	20,489
1992	8,997	778	1,000	2,834	7,048	20,656

Source: USDA, Cropping Practices Surveys.

**Figure 4
Total nutrient consumption, by crop**



ent use stems from a drop in the proportion of soybean acreage fertilized and reductions in soybean acreage.

Wheat, the second most important crop with respect to nutrient use, received 2.8 million tons in 1992, or 14 percent of the U.S. total. This is a considerable increase from the 708,000 tons consumed in 1964 when wheat ranked third in total tonnage behind corn and cotton. Nitrogen consumption on wheat has risen the most over this period as total use of nitrogen increased by over 435 percent, while wheat acreage was up 30 percent from 1964. This rapid increase in nitrogen use is a result of increased application rates that have more than doubled and an increase in the proportion of wheat acreage fertilized.

While detailed data on nutrient use by crops other than corn, cotton, soybeans, and wheat are not col-

lected in any consistent manner, an estimate for other crops can be developed. This estimate is developed by adding the estimated total nutrient use on the four selected crops, and subtracting it from the total nutrient use. In 1964, crops other than corn, cotton, soybeans, and wheat used an estimated 5.4 million tons of nutrient, or 51 percent of the U.S. total. By 1992, these other crops used 7 million tons of nutrients and had a 33-percent share of the total use. Recently, USDA PDP surveys have provided an estimate of nutrients applied to vegetable and fruit crops for the 1990-93 period. The estimates have been reported elsewhere (USDA/NASS, 1991b, 1992b, 1993b, 1994b).

Agricultural Chemical Use on Major Field Crops

As indicated earlier, corn, cotton, soybeans, and wheat have been included in the annual fertilizer survey and all the eight pesticide use surveys. Fall potato production is pesticide-intensive and has been included in six surveys between 1966 and 1992. Our report of agricultural chemical use by crop and chemical type is focused on the crops mentioned above. Fertilizer and pesticide use on vegetables and fruits has been surveyed under the Pesticide Data Program since 1990, and the collected information has been reported (USDA/NASS, 1991b, 1992b, 1993b, 1994b).

Pesticide Use on Major Field Crops by Crop and Active Ingredient

Corn, soybeans, wheat, and cotton are major users of herbicides. Insecticides are also used extensively in corn and cotton production. Fall potato production requires the use of herbicides, insecticides, and fungicides. As shown in table 2, corn, soybeans, wheat, cotton, and fall potatoes have accounted for 86 percent of total herbicide use and 54 percent of total insecticide use in the 1990's. Fungicide use in fall potato production represented a very small proportion of total fungicide use in U.S. agriculture.

Among the five field crops discussed in this section, corn has accounted for 66 percent of herbicide use and 55 percent of insecticide use in the 1990's. Soybean production is the second leading herbicide user, with a 21-percent share. Cotton used 7 percent, wheat 5 percent, and fall potatoes 1 percent of herbicide use on the five field crops. Cotton accounted for 36 percent of insecticide use, and the remaining 9 percent of insecticides were applied to fall potatoes.

This section reports various aspects of pesticide applications to the five crops, including commonly used

active ingredients, target species, timing and method of applications, the percentage of acres treated, the application rate, and total pesticide use. Many pesticides were subject to or are under EPA's special reviews,⁵ and pesticide uses registered prior to November 1, 1984, are in the reregistration process.⁶ Outcomes of special reviews and status of pesticide reregistration are briefly discussed in this section (also see tables 5-9).

Corn

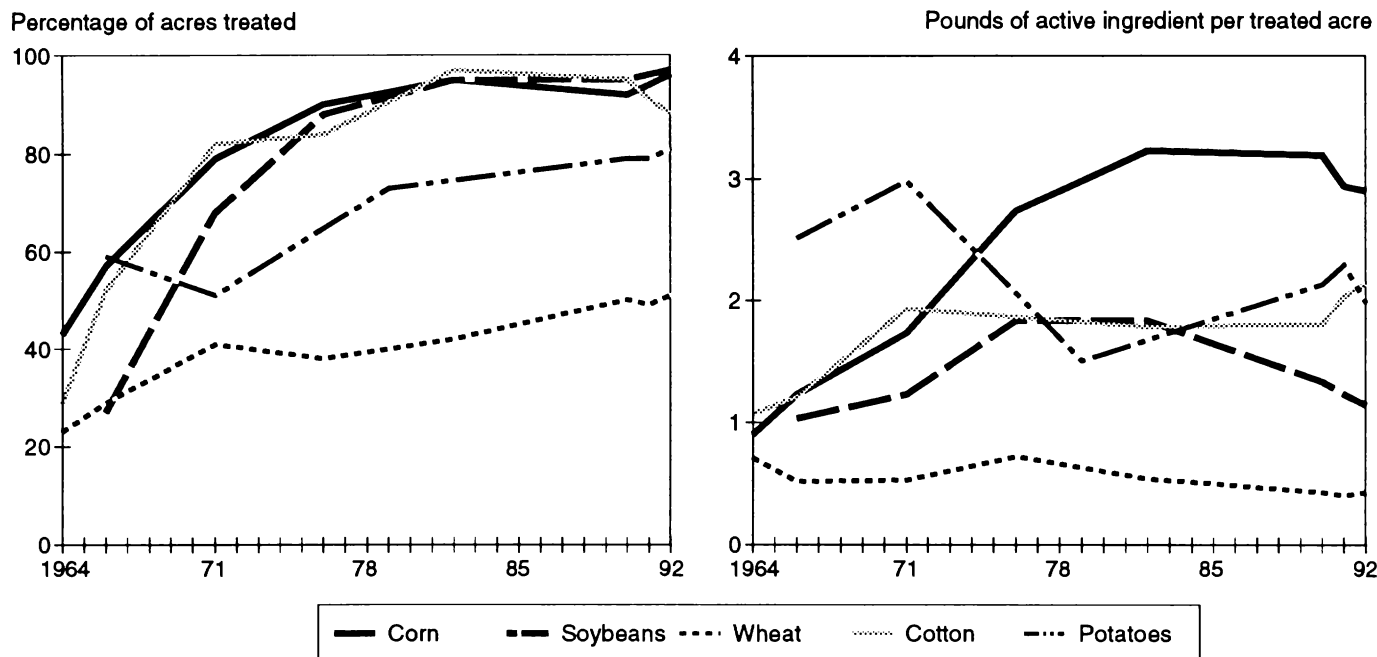
In 1964, an estimated 26 million pounds of herbicides were used on 43 percent of corn acres, compared with 199 million pounds applied to 96 percent of acres in 1992 (table 5). (Note that figures in tables 5-8 are survey quantities, and are expanded to represent total U.S. acreage in table 2.) The percentage of corn acreage treated with herbicides increased substantially during the 1960's and 1970's, and has leveled off around 95 percent since the 1980's (fig. 5). Along with the increasing percentage of acreage treated with herbicides, the application rate per treated acre also increased from 0.90 pounds in 1964 to the peak level of 3.23 pounds in 1982 (fig. 5). These two factors, combined with increased planted acres, pushed herbicide use on corn toward the record high of 343 million pounds in 1982. Since 1982, with stable percentage of acres treated, steadily declining application rates, and fewer planted acres, annual herbicide use on corn declined to around 218 million pounds in the early 1990's.

Atrazine and 2,4-D were the most heavily used herbicides in 1964 and in 1992 atrazine was still the leading herbicide, with 55 million pounds being ap-

⁵When a pesticide is found to show the potential of exceeding the EPA's health and environmental criteria, EPA needs to follow a set of procedures to determine whether any regulatory measures are required to reduce risks to acceptable levels (USEPA, 1991). Potential risks are measured by adverse effects to human health or the environment, magnitude of exposure of humans and other nontarget organisms, and the size of the population at risk. The risks of a use are compared with its benefits, which are evaluated by assessing the availability, efficacy, and cost of alternative control methods; and impacts on users, consumers, and other parties if the pesticide use is canceled.

⁶Rising concerns about potential risks to human health and the environment associated with pesticide use resulted in the 1972 amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which increased the stringency of the health and safety data required to support a pesticide registration. The amendments also required that all existing pesticides be reregistered using current health and environmental standards. The FIFRA 1988 amendments require EPA to complete the reregistration review of each registered product containing any active ingredient initially approved before November 1, 1984 (USEPA, May 1992).

Figure 5
Herbicide use on major field crops, 1964-92



plied, followed by metolachlor (41 million pounds), alachlor (40 million pounds), and cyanazine (27 million pounds). These four materials accounted for 82 percent of the quantity of herbicides used in corn production in 1992. Metolachlor was introduced in the mid-1970's and its use has increased over the last 10 years. Alachlor was introduced in the late 1960's and achieved its greatest usage during the 1970's and early 1980's. Since 1987, alachlor use has been restricted such that it has to be applied by or under direct supervision of a certified applicator. Cyanazine was introduced in the early 1970's and its use has increased slightly over the last 10 years.

Atrazine controls broadleaf weeds and several grass weeds. It may be applied to the soil preemergence and postemergence (before or after planting), giving the grower flexibility in timing of application. Atrazine use was 10 million pounds in 1964, peaked at 84 million pounds in 1976, and declined to 50 to 60 million pounds annually in the 1990's. The application rate per treated acre for atrazine has also changed over time. In 1964, the rate was 1.34 pounds per acre, during the later 1960's and through the early 1980's the rate ranged between 1.44 and 1.54 pounds, in recent years the rates were 1.22 in 1990, 1.14 in 1991, and 1.12 in 1992. When atrazine was introduced in the

early 1960's, band applications were frequently used. With a band application, about one-third of the soil surface receives the herbicide treatment. Weed control in the row middles was accomplished by mechanical cultivations. Later, farmers switched to broadcast treatments, substituting chemical control for mechanical cultivation. The use of 2,4-D has declined from a high of 15 million pounds in 1966 to 2.8 million pounds in 1992. 2,4-D controls only broadleaf weeds and is applied postemergence at a rate of 0.5 pound per acre.

Insecticides are used in corn production primarily to control corn rootworm larvae. Granular formulations are placed in a band in the seed row to prevent the larvae from feeding on the corn roots. Since 1966, 30 to 40 percent of the corn acreage has been treated for insect control, with a declining trend since 1976 (table 5 and fig. 6). Rootworms tend to become a problem when corn follows corn in a rotation. In 1990, 37 percent of the corn grown in the 10 major producing States followed a previous corn crop and 25 percent of the acreage had been in corn production for 3 years. Other important insects in corn production include European corn borers, cutworms, and mites in the dryer western parts of the Corn Belt.

Table 5—Herbicide and insecticide use in corn production

Pesticides	1964	1966	1971	1976	1982	1990	1991	1992
<i>Million pounds active ingredient or acres</i>								
Herbicides								
Alachlor (A,SR) ¹			8.4	58.2	52.3	36.0	37.2	40.1
Atrazine (A)	10.2	21.1	52.0	83.8	69.7	58.1	52.1	54.9
Butylate (A)			5.8	24.3	54.9	14.2	8.5	8.1
CDAA (AC)	2.6	3.9						
Cyanazine (A,SR)				10.4	20.7	23.4	23.2	26.7
Dicamba (A)			0.3	1.4	2.1	4.5	3.6	5.1
EPTC (A)			0.3	8.2	8.3	30.6	14.4	10.6
Linuron (A,SR)		0.3	0.8	1.6	0.3		0.1	0.1
Metolachlor (A)					21.7	35.9	38.8	41.3
Propachlor (A)		2.2	21.3	7.7	3.5	2.0	1.5	1.5
Simazine (A)			0.9	2.4	3.3	2.0	1.1	1.1
2,4-D (A,SR)	9.7	14.7	9.1	8.0	5.1	4.0	2.8	2.8
Other	3.0	4.1	2.2	1.1	1.5	6.8	6.5	6.6
Survey quantity	25.5	46.3	101.1	207.1	243.4	217.5	189.8	198.9
Surveyed acres	65.8	66.3	74.1	84.1	79.4	74.2	68.6	71.4
Percent acres treated	43	57	79	90	95	92	94	96
Lbs a.i./treated acre	0.90	1.23	1.73	2.74	3.23	3.19	2.94	2.90
Insecticides								
Aldrin (SR) ¹	10.7	14.2	7.8	0.9				
Bufencarb (AC)			3.6					
Carbaryl (A)	0.1	0.5	1.6	2.1	0.2			
Carbofuran (A,SR)			2.7	9.9	5.2	2.6	2.3	1.6
Chlorpyrifos (A)					3.9	5.6	6.7	6.2
Diazinon (A,SR)	1.5	4.0	2.0	0.8	0.2		0.1	
Fonofos (A)				5.0	5.1	2.8	2.9	2.0
Heptachlor (SR)	1.1	1.5	1.1	1.6				
Parathion (SR)	0.7	1.9	1.3	0.6	0.1			
Phorate (A)	1.0		2.7	5.8	3.8	1.7	1.3	1.0
Terbufos (A)				2.5	8.7	10.2	6.0	6.3
Other	0.6	1.5	2.7	2.8	2.9	0.3	1.5	1.2
Survey quantity	15.7	23.6	25.5	32.0	30.1	23.2	20.8	18.3
Surveyed acres	65.8	66.3	74.1	84.1	79.4	74.2	68.6	71.4
Percent acres treated	10	33	35	38	37	31	30	29
Lbs a.i./treated acre	2.39	1.08	0.98	1.00	1.02	1.01	1.01	0.88

¹A: List A chemical in reregistration; AC: List A chemical not supported (canceled);

B: List B chemical in reregistration; BC: List B chemical not supported (canceled);

C: List C chemical in reregistration; CC: List C chemical not supported (canceled);

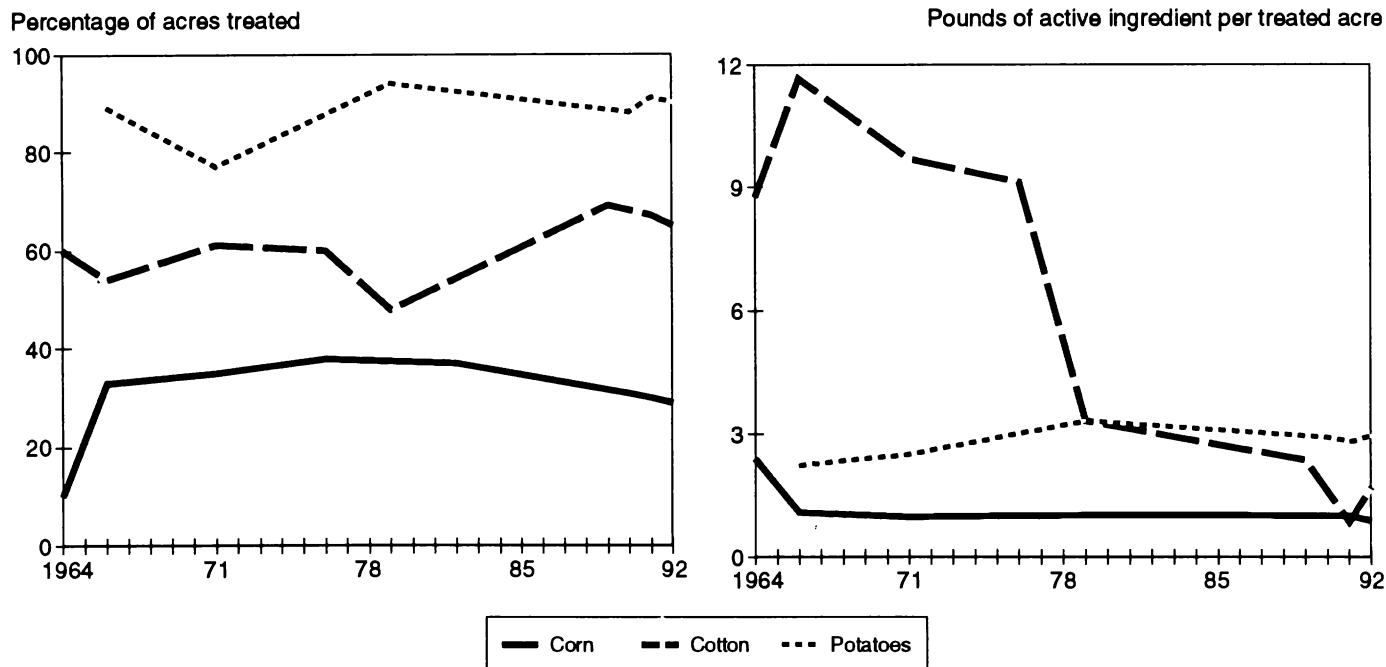
D: List D chemical in reregistration; DC: List D chemical not supported (canceled);

N: not in reregistration nor Special Review;

SR: the chemical either completed a Special Review or is in a Special Review.

Sources: See appendix B, table 1 for USDA pesticide surveys; See USEPA (1993) for Special Review and reregistration.

Figure 6
Insecticide use on major field crops, 1964-92



In 1964, about 16 million pounds of insecticides were applied to 10 percent of the corn acreage. Aldrin was the most commonly used insecticide during the 1960's and early 1970's. In 1974, use of aldrin in crop production was canceled due to carcinogenicity, bio-accumulation, and wildlife hazard concerns. Carbofuran was the most heavily used insecticide in 1976 but its use has declined steadily in recent years because of its acute toxicity to birds. Granular formulations of carbofuran for corn rootworm larvae control were canceled at the end of the 1994 crop year. The insecticide application rate in corn production was fairly stable around 1.00 pound per treated acre since the early 1970's, but was reduced to 0.88 pound in 1992 (fig. 6). Chlorpyrifos and terbufos substituted for carbofuran and became the most heavily used insecticides in 1992, accounting for 68 percent of insecticides used in corn production.

Soybeans

The quantity of herbicides used in soybean production peaked at 125 million pounds in 1982 as the application rate topped at 1.83 pounds per treated acre and the planted area rose to 72 million acres (table 6). At the same time, the percentage of soybean acreage treated with herbicides rose from 27 percent in 1966 to 95 percent in 1982 (fig. 5). By 1992, total usage

had declined to 59 million pounds as the application rate fell to 1.14 pounds, the planted area shrank to 59 million acres, and the percentage of acreage treated stabilized at around 95 percent.

Trifluralin was the most heavily used herbicide through the 1964-92 period. It is applied as a broadcast, pre-plant, soil-incorporated treatment to control many broadleaf and grass weeds. Chloramben was used extensively during the 1960's and up to 1982. Since that time, its use has dropped dramatically. Chloramben was generally applied as a band application in the crop row at planting time. Alachlor is generally applied as a preemergence broadcast treatment.

In the late 1980's, several new herbicides were introduced for weed control in soybean production. These include chlorimuron, imazaquin, and imazethapyr. Chlorimuron is applied postemergence at a rate of 0.02 to 0.03 pound per acre to control broadleaf weeds. Imazaquin and imazethapyr can be applied pre-plant, preemergence, and postemergence primarily for broadleaf weed control, although some grass weeds are also controlled when applied pre-plant or preemergence. Imazaquin is applied at about 0.1 pound and imazethapyr at 0.06 pound per acre. In addition, growers in recent years have increased their use of the

Table 6—Herbicide use in soybean and wheat production

Herbicides/crop	1964	1966	1971	1976	1982	1990	1991	1992
<i>Million pounds active ingredient or acres</i>								
Soybean								
Acifluorfen (N) ¹						1.1	0.9	1.1
Alachlor (A,SR)			6.3	29.6	30.9	14.7	12.8	10.2
Bentazon (A)				3.8	8.1	6.1	4.2	4.8
CDAA (AC)	0.9	1.0						
Chloramben (AC)	1.3	3.7	9.3	4.4	6.0	0.7	0.2	
Chlorimuron (N)						0.3	0.2	0.2
Clomazone (N)						2.7	1.9	1.4
Dinoseb (SR)				3.7	4.3			
Ethalfuralin (B,SR)						2.4	1.4	0.9
Glyphosate (A)						2.7	2.4	2.4
Imazaquin (N)						1.0	0.8	0.9
Imazethapyr (N)						0.4	0.7	0.9
Linuron (A,SR)		0.4	0.8	6.2	5.8	2.0	1.0	0.5
Metolachlor (A)					12.9	9.9	7.6	5.9
Metribuzin (A)				5.2	10.2	3.6	2.7	2.2
Naptalam (A)		0.9	3.0	3.9	4.4			
Pendimethalin (A)						6.8	7.9	9.7
Trifluralin (A,SR)	0.2	2.2	6.0	21.1	30.7	17.6	16.3	15.6
Other	1.8	2.2	11.1	3.2	11.9	2.4	1.9	2.1
Survey quantity	4.2	10.4	36.5	81.1	125.2	74.4	62.9	58.8
Surveyed acres	31.7	37.4	43.5	50.3	72.0	57.8	53.2	53.1
Percent acres treated	na	27	68	88	95	95	96	97
Lbs a.i./treated acre	na	1.03	1.23	1.83	1.83	1.33	1.23	1.14
Wheat								
Barban (BC) ¹				0.2	0.1			
Bromoxynil (B)				0.9	0.7	0.5	0.4	0.6
Dicamba (A)		0.2	0.1	1.5	0.7	0.5	0.4	0.5
Diclofop-methyl (B)					0.7	0.6	0.2	0.7
Difenzoquat (A)					0.4	0.2		
MCPA (A)	0.2	0.3	1.1	1.2	1.8	2.5	2.4	2.9
Picloram (A)				0.4				
Terbutryn (SR)				0.8				
Triallate (B,SR)				0.6	2.4	1.0	0.8	1.1
Trifluralin (A,SR)					0.8	0.8	0.6	0.5
2,4-D (A,SR)	8.7	6.9	8.9	15.5	10.1	6.0	4.4	5.4
Other	0.2	0.8	1.5	0.8	0.3	0.6	0.6	0.7
Survey quantity	9.1	8.2	11.6	21.9	18.0	12.7	9.8	12.4
Surveyed acres	55.7	54.5	53.8	80.2	79.8	59.0	50.5	56.0
Percent acres treated	23	29	41	38	42	50	49	51
Lbs a.i./treated acre	0.71	0.52	0.53	0.72	0.54	0.43	0.40	0.43

¹See the footnote in table 5.

na = not available.

Sources: See appendix B, table 1 for USDA pesticide surveys; See USEPA (1993) for Special Review and reregistration.

postemergence grass herbicides, fluazifop and sethoxydim, which are applied at 0.14 pound and 0.2 pound per acre, respectively. The above materials have substituted for alachlor, which is applied at 2.0 pounds per acre, and thus resulted in the downward trend in soybean herbicide use.

Wheat

The data presented in table 6 are for all wheat, however there are differences in herbicide use among winter, spring, and durum wheat. The surveys from 1964 and 1982 did not distinguish between classes of wheat, but the surveys since 1990 presented information for each class. Pesticide use in wheat production by class in the 1990's has been reported (USDA/NASS, 1991a, 1992a, 1993a, 1994a).

For all wheat, the percentage of acreage treated with herbicides registered an upward trend, increasing from 23 percent in 1964 to 42 percent in 1982 and to 50 percent in the 1990's (fig. 5). Only about 30 percent of the winter wheat acreage is treated with herbicides, compared with 90 to 95 percent for spring and durum wheat. Winter wheat is grown primarily in the Central and Southern Plains and the Pacific Northwest. Winter wheat is planted in the fall and is an excellent competitor with weeds. Spring wheat and durum wheat are grown primarily in the Northern Plains and planted in the spring of the year. The spring preparation of the seedbed provides a good medium for both crop and weed seed germination; consequently, herbicides are needed and used more.

Dicamba, MCPA, and 2,4-D have been used extensively in wheat production during the past 30 years. They are applied postemergence and control a wide spectrum of broadleaf weeds. Bromoxynil, another postemergence broadleaf weed herbicide, has also been used since the mid-1970's. Grass weeds, primarily wild oats and foxtail (pigeon grass), are a problem in the spring and durum wheat area. Triallate is used for wild oats control and is generally applied at or after planting and is incorporated into the soil. Trifluralin is used primarily for foxtail grass control and is applied in the same manner as triallate. Often, these two materials are mixed and applied together. Diclofop-methyl controls wild oats and foxtail and is applied as a postemergence treatment. In the 1980's, several new active ingredients were introduced for weed control in wheat production but they have not gained a significant share of the market. These materials include chlorsulfuron, fexoxaprop, imazamethabenz, metsulfuron, thifensulfuron, and tribenuron.

Cotton

Cotton herbicide use increased from less than 5 million pounds in 1964 to 19 million pounds in 1992 (table 7). The percentage of the cotton acreage treated with herbicides was about 30 percent in 1964, peaked at 97 percent in 1982, and declined to around 90 percent in the 1990's (fig. 5). As discussed earlier, herbicide use in corn, soybean, and wheat production declined appreciably after the peak in 1982 because of the introduction of new materials applied at lower rates and fewer planted acres. In contrast, herbicide use in cotton production increased from 1982 to 1990 as higher rates were applied to more planted acres. The herbicide application rate per treated acre in cotton production rose drastically in the 1960's, stabilized at a rate around 1.85 pounds per treated acre during the 1970's and 1980's, and increased to 2.14 pounds in 1992. During the past 15 to 20 years, no new herbicides have been developed for weed control in cotton production. However, several materials are on the horizon, which should lower the herbicide application rate in cotton production.

Diuron and MSMA have been used throughout the 30-year period with trifluralin being used extensively since 1966. Nine active ingredients are currently used for weed control in cotton production with trifluralin, MSMA, and flumeturon being the most heavily used, accounting for 53 percent of the quantity applied in 1992. Trifluralin is generally applied pre-plant, soil-incorporated to control annual grasses and small-seeded broadleaf weeds as they germinate. Flumeturon can be applied either pre- or post-emergence to control grass and broadleaf weeds. MSMA is applied postemergence for both grass and broadleaf control, and is often combined with other herbicides to broaden the spectrum of control.

Cotton growers currently and over time have used a large number of insecticides to control insects, such as boll weevils, tobacco budworms, and cotton bollworms. Insecticide use in cotton production registered a sharp downward trend since the 1960's, started with a total use of 78 million pounds and an application rate of 8.8 pounds per treated acre in 1964 to a total use of 11 million pounds at a rate of 1.7 pounds per treated acre in 1992 (table 7 and fig. 6). The proportion of cotton acreage treated with insecticides ranged from a low of 48 percent in 1979 to a high of 69 percent in 1989. The low pest pressure in 1966 and 1979 contributed to the small percentages of acreage treated in these 2 years. The low pest pressure in 1979 and the substitution of synthetic pyrethroids for toxaphene contributed to the sharp decrease in the application rate in 1979.

Table 7—Herbicide and insecticide use in cotton production

Pesticides	1964	1966	1971	1976	1982	1990	1991	1992
<i>Million pounds active ingredient or acres</i>								
Herbicides								
Cyanazine (A,SR) ¹					0.6	1.3	1.7	1.9
Diuron (A)	1.0	0.9	0.6	0.4	0.3	0.6	0.5	0.7
DSMA (B)				1.5	0.9	0.9	0.8	0.6
Flumeturon (A)			3.3	5.3	2.9	1.9	2.5	2.4
Linuron (A)				0.4	0.2			
MSMA (B,SR)	1.0	0.8	7.6	1.8	3.6	2.7	3.2	3.1
Norflurazon (A)					0.5	1.1	1.3	1.1
Pendimethalin (A)					0.6	1.5	1.6	1.3
Prometryn (A)				0.7	1.0	1.5	1.8	1.6
Trifluralin (A,SR)		2.6	4.5	7.0	4.3	4.4	5.6	4.6
Other	2.6	2.2	3.6	1.2	2.4	0.9	1.1	1.7
Survey quantity	4.6	6.5	19.6	18.3	17.3	16.8	20.1	19.0
Surveyed acres	14.8	10.3	12.4	11.7	10.0	9.8	10.9	10.1
Percent acres treated	29	52	82	84	97	95	91	88
Lbs a.i./treated acre	1.07	1.21	1.93	1.86	1.78	1.80	2.03	2.14
Pesticides ²	1964	1966	1971	1976	1979	1989	1991	1992
<i>Million pounds active ingredient or acres</i>								
Insecticides								
Acephate (A) ¹					0.4	0.5	0.6	0.6
Aldicarb (A,SR)				0.5	0.5	1.2	0.6	0.6
Azinphosmethyl (A)	0.3	0.2	0.3	0.2	0.3	0.8	0.3	0.5
Carbaryl (A,SR)	4.5	1.6	1.2	0.4				
Chlordimeform (SR)				4.4	0.9	0.2		
Chlorpyrifos (A)						0.4	0.7	0.4
Cyfluthrin (N)						0.1	0.1	
Cypermethrin (B)						0.4	0.1	
DDT (SR)	23.6	19.2	13.2					
Diclotophos (A)					0.3	0.5	0.4	0.4
Endrin (SR)	1.9	0.5	1.1	0.3				
EPN (SR)				6.1	2.5			
Esfenvalerate (N)						0.2	0.1	0.1
Fenvalerate (B)					0.4	0.1		
Lamda-cyhalothrin (N)						0.1	0.1	0.1
Malathion (A)	1.8	0.6	0.7			3.9		0.2
Methomyl (A)				0.6	0.4	0.1	0.2	0.3
Methyl parathion (A)	8.8	7.3	23.0	20.0	4.7	4.6	1.5	3.1
Monocrotophos (SR)				1.5		0.2		
Parathion (SR)	1.6	2.2	2.6	0.7		0.3	0.2	0.2
Permethrin (B)					0.6	0.1		
Profenofos (B)						0.8	0.3	1.3
Sulprofos (A)						0.2		0.5
Thiodicarb (B)						0.5	0.2	0.7
Toxaphene (SR)	26.9	27.3	28.1	26.3	2.8			
Other	8.6	4.1	2.4	2.8	8.2	1.8	0.9	2.0
Survey quantity	78.0	64.9	73.4	64.1	22.0	17.0	6.3	11.0
Surveyed acres	14.8	10.3	12.4	11.7	13.8	10.5	10.9	10.1
Percent acres treated	60	54	61	60	48	69	67	65
Lbs a.i./treated acre	8.78	11.67	9.70	9.13	3.32	2.35	0.86	1.68

¹See the footnote in table 5.²Herbicides and insecticides were surveyed in different years.

Sources: See appendix B, table 1 for USDA pesticide surveys; See USEPA (1993) for Special Review and reregistration.

Toxaphene, DDT, and methyl parathion were the most heavily used insecticides on cotton to control tobacco budworms, bollworms, and boll weevils during the first 3 survey periods. They were commonly applied as a combination. Use of DDT in crop production was canceled in 1972, and was substituted by EPN. Chlordimeform was also used extensively as an ovicide to destroy budworm and bollworm eggs before they hatched, and its use was voluntarily withdrawn in 1988. Methyl parathion was still the most heavily used insecticide in cotton production in 1979, primarily for boll weevil control, at a rate of 0.5 pound per acre. EPN was second in quantity but its use had decreased relative to 1976. EPN use in crop production was voluntarily withdrawn in 1987 because of neurotoxicity concerns and hazards to aquatic organisms.

The drastic decrease in cotton insecticide use from 64 million pounds in 1976 to 22 million pounds in 1979 was attributed partially to an almost 90-percent reduction in the use of toxaphene. The use of toxaphene in crop production was canceled in 1983 because of carcinogenicity concerns, chronic hazards to wildlife, and acute toxicity to aquatic organisms. In 1977, fenvalerate and permethrin, two synthetic pyrethroids, were granted emergency registration for budworm and bollworm control in cotton production. In 1979, 400,000 pounds of fenvalerate and 600,000 pounds of permethrin were used in cotton production. However, these quantity figures mask the importance of these two materials. Fenvalerate was applied at a rate of 0.1 pound and permethrin at 0.12 pound per treatment in 1979. Permethrin was used in 17 percent and fenvalerate in 13 percent of all acre-treatments (acres treated times number of treatments), compared with 27 percent for methyl parathion.

Methyl parathion was the most heavily used insecticide in cotton production in 1989, followed by malathion. Malathion use was high in 1989 because of the boll weevil eradication program in Georgia and southern Alabama. Fenvalerate and permethrin use declined and were substituted by newer synthetic pyrethroids (cypermethrin and esfenvalerate), cyfluthrin, and lambda-cyhalothrin. These newer materials are applied at application rates of 0.02 to 0.06 pound per treatment, and thus drastically reduced the insecticide application rate in 1991 and 1992.

Potatoes

Fall potatoes are grown across the Northern United States from Maine to Washington. Climatic factors affect pesticide use across this broad production area. Weeds are more of a problem in the high-rainfall East

and irrigated production areas of the Pacific Northwest, compared with the low-rainfall areas of North Dakota and Minnesota. Insects, on the other hand, are a fairly uniform problem throughout all production areas. Disease problems are highest in the humid Eastern States and lowest in the more arid Western States. The percentage of potato acreage treated with herbicides and application rates per treated acre are shown in figure 5.

Currently and over time, fall potato growers have used a limited number of herbicides for weed management. In 1966, inorganic herbicides dominated with 1.2 million pounds being used (included in "other" category, table 8). Dinoseb was second in importance with 740,000 pounds being used. In 1971, dinoseb was the most heavily used herbicide, followed by EPTC. Dinoseb was applied 1 to 3 days before the crop emerged at a rate of 2 to 4 pounds per acre (lower rates are for broadleaf weed control and higher rates are applied to annual grass). EPTC is applied pre-plant or after planting prior to weed germination (numerous broadleaf and grass weeds), at a rate of 3 to 4 pounds per acre. EPTC must be incorporated into the soil because it is readily lost by volatilization. It is most effective where rainfall is low.

Dinoseb use declined dramatically in 1979 and its use in fall potato production was canceled in early 1987 because of birth defect concerns. EPTC was the most heavily used herbicide in 1979, followed by metribuzin. However, metribuzin (at a rate of 1.0 pound per acre) accounted for 53 percent of the acre-treatments, compared with 17 percent for EPTC. Metribuzin was a relatively new herbicide in 1979 and it may be applied as either a preemergence or postemergence treatment to control broadleaf weeds and grasses. It requires moisture shortly after application when used as a preemergence treatment and, therefore, is widely used in irrigated areas and in the eastern production regions where rain is more frequent.

In the 1990's, EPTC and metribuzin were still the two most commonly used herbicides in fall potato production. Metribuzin was applied to 60 percent and EPTC to 30 percent of the potato acreage. Metolachlor and pendimethalin were also used on 10 and 15 percent of the acreage, respectively. Both materials have pre-emergence activity and control grass weeds as they germinate. Metolachlor is applied at 2.0 pounds and pendimethalin at 1.0 pound per acre.

Growers use a wide variety of insecticides to control insects in fall potato production. Colorado potato bee-

Table 8—Pesticide use in potato production

Pesticides	1966 ¹	1971 ¹	1979 ²	1990 ²	1991 ²	1992 ²
<i>Thousand pounds of active ingredients or acres</i>						
Herbicides						
Dinitro group (BC) ³	743	1,398	119			
EPTC (A)		581	481	1,073	1,192	929
Glyphosate (A)				22	26	18
Linuron (A)	131	29	69	58	53	44
Metolachlor (A)				159	243	204
Metribuzin (A)			247	362	321	322
Pendimethalin (A)				135	175	159
Sethoxydim (B)				5	7	8
Trifluralin (A,SR)		110	40	40	29	28
Other	1,346	60	151	1	0	0
Survey quantity	2,220	2,178	1,107	1,855	2,046	1,712
Surveyed acres	1,497	1,432	1,012	1,100	1,131	1,068
Percent acres treated	59	51	73	79	79	81
a.i. rate/treated ac	2.51	2.98	1.50	2.13	2.29	1.98
Insecticides						
Aldicarb (A,SR) ³			805	43		
Azinphosmethyl (A)		191	92	39	61	66
Carbaryl (A,SR)	401	357	134	30	27	27
Carbofuran (A,SR)			82	146	108	143
Cryolite (A)					165	206
DDT (SR)	571	77				
Diazinon (A,SR)	321			19	41	57
Dimethoate (A,SR)			19	7	10	12
Disulfoton (A)	532	1,047	599	299	238	195
Endosulfan (A)	119	182	156	101	141	156
Esfenvalerate (N)				11	15	10
Ethoprop (A)				663	408	386
Fonofos (A)			170	47	42	121
Methamidophos (A)			345	227	322	368
Oxamyl (A)				14	25	21
Parathion (SR)	389	167	89	19	31	
Permethrin (B)			6	16	19	16
Phorate (A)		254	408	991	1,119	856
Phosmet (A)				18	38	55
Phosphamidon (AC)			26	63	56	8
Sulfur (A)			104	52		
Toxaphene (SR)	124	142				
Other	515	353	127	16	23	124
Survey quantity	2,972	2,770	3,162	2,821	2,889	2,827
Surveyed acres	1,497	1,432	1,012	1,100	1,131	1,068
Percent acres treated	89	77	94	88	91	90
a.i. rate/treated ac	2.23	2.51	3.32	2.91	2.81	2.94

Continued--

Table 8—Pesticide use in potato production—Continued

Pesticides	1966 ¹	1971 ¹	1979 ²	1990 ²	1991 ²	1992 ²
<i>Thousand pounds of active ingredients or acres</i>						
Fungicides						
Captafol (SR) ³			204			
Chlorothalonil (A)			347	375	272	443
Copper	31	29	73	93	75	80
Iprodione (B)				59	51	80
Mancozeb (A,SR)				1,063	1,415	1,590
Maneb (A,SR)	1,499	961	2,631	528	587	547
Metalaxyl (A)				23	23	48
Metiram (A,SR)			236	62	50	31
Sulfur (A)			389		40	108
Triphenyltin hydroxide (N)				27	47	46
Zineb (SR)	1,273	109				
Other	728	3,025	53	28	28	18
Survey quantity	3,531	4,124	3,933	2,258	2,588	2,991
Surveyed acres	1,497	1,432	1,012	1,100	1,131	1,068
Percent acres treated	24	49	64	67	69	72
a.i. rate/treated ac	9.83	5.88	6.07	3.06	3.32	3.89

¹All potatoes.²Fall potatoes.³See the footnote in table 5.

Sources: See appendix B, table 1 for USDA pesticide surveys; See USEPA (1993) for Special Review and reregistration.

tles, aphids, and leafhoppers constitute the major insect problems. The Colorado potato beetle has developed some resistance to a number of organophosphorus insecticides, and to some of the newer synthetic pyrethroids.

As shown in table 8 and figure 6, insecticide use in fall potato production has ranged from a low of 2.8 million pounds with 77 percent of the acres treated in 1971 to a high of 3.2 million pounds and 94 percent of the acres treated in 1979. The application rate fluctuated, with no obvious trend, ranging from 2.2 (in 1966) to 3.3 (in 1979) pounds per treated acre. In the 1990's, 3 million pounds of insecticides were applied to 90 percent of acres at a rate of 2.9 pounds per treated acre.

DDT, disulfoton, carbaryl, and parathion were the most heavily used insecticides in the 1966 fall potato production. Disulfoton use doubled by 1971 but its use has since declined in importance. Disulfoton is a systemic insecticide that is used as a banded application in the seed row at planting. It gives early season control of foliage feeding insects and also affords protection against soil-dwelling wireworms. DDT use declined dramatically by 1971 and its use was canceled in 1972. Carbaryl and parathion were still used in 1971 but their importance had steadily declined.

Parathion was voluntarily withdrawn from fall potato production in 1991 because of acute human poisoning.

Aldicarb was the most heavily used potato insecticide in 1979. It is a systemic insecticide and controls aphids, flea beetles, leafhoppers, and early generations of the Colorado potato beetle. Its importance as a potato insecticide was short-lived because, in many areas, the Colorado potato beetle developed resistance and aldicarb was also easily leached into the ground water. In 1992, the registration of aldicarb use in fall potato production was withdrawn by the manufacturer.

Disulfoton was the second most heavily used insecticide in 1979 followed by phorate and methamidophos. Phorate is a soil-applied systemic insecticide placed in the seed row at planting. It controls early-season foliage-feeding insects as well as wireworms. Methamidophos is applied to the potato foliage to control later generations of flea beetles, leafhoppers, and Colorado potato beetles. Growers frequently apply disulfoton and phorate at planting and methamidophos later in the season.

In the 1990's, phorate, ethoprop, and methamidophos have been used in the largest quantities. Ethoprop is applied either broadcast soil-incorporated before planting or as a banded application at planting. It is used

Table 9—EPA regulatory actions and special review status on major pesticides used in field crop production, 1972 - June 1993

Pesticide and concerns	Action of chemical	Regulatory action and date
Alachlor • Carcinogenicity	Control of grasses and broadleaf weeds in corn and soybeans.	<ul style="list-style-type: none"> • Restricted use and label warning, 1987. • Ongoing pre-Special Review for ground-water contamination.
Aldicarb • Acute toxicity • Groundwater contamination	Systemic insecticide for aphids, flea beetles, leafhoppers, and Colorado potato beetles in potato and cotton production.	<ul style="list-style-type: none"> • Cancel use on banana, posing dietary risk concern, 1992.
Aldrin • Carcinogenicity • Bio-accumulation • Hazards to wildlife • Other chronic effects	Control of soil insects.	<ul style="list-style-type: none"> • All uses but termite control canceled, 1974.
Captafol • Carcinogenicity	Control early and late blight on potatoes.	<ul style="list-style-type: none"> • All uses canceled, 1987.
Carbaryl • Carcinogenicity • Mutagenicity • Developmental toxicity	Control various insects in field, vegetable, and fruit crops. Used extensively by homeowners.	<ul style="list-style-type: none"> • Pre-Special Review stipulates a data need and label change be considered in reregistration, 1980. List A, in data waiting/review stage.
Carbofuran (granular) • Wildlife effects	Control corn rootworm larvae.	<ul style="list-style-type: none"> • Eight uses canceled, 1990. • Phase out most uses, 1991.
Chlordimeform • Carcinogenicity	Control bollworms and tobacco budworm on cotton.	<ul style="list-style-type: none"> • All uses canceled, 1988. • Use of existing inventory, 1989.
Cyanazine • Developmental toxicity	Control of grass and broadleaf weeds in corn, cotton, and sorghum.	<ul style="list-style-type: none"> • Protective clothing and hazard warning statement, 1988.
DDT • Carcinogenicity • Bio-accumulation • Hazards to wildlife • Other chronic effects	Broad spectrum insecticide.	<ul style="list-style-type: none"> • All uses canceled (except control of vector diseases, health quarantine, and body lice), 1972.
Diazinon • Avian hazard	Control various insects on field, vegetable, fruit, and nut crops.	<ul style="list-style-type: none"> • All use on golf course and sod farms canceled, 1990.
Dimethoate • Carcinogenicity • Fetotoxicity • Mutagenicity • Reproductive effects	Control mites and leafminers in corn, cotton, sorghum, soybeans, and vegetables.	<ul style="list-style-type: none"> • Dust formulation denied and label change, 1981.
Dinoseb • Developmental toxicity • Reproductive effects • Acute effects	Contact herbicide desiccant.	<ul style="list-style-type: none"> • Emergency suspension, 1986. • All uses canceled (except certain crops in Pacific Northwest during 1987-89), 1987.
EBDC [Mancozeb, Maneb, Metiram, Nabam, Zineb] • Carcinogenicity • Developmental toxicity	Fungicides for fruits, vegetables, and field crops.	<ul style="list-style-type: none"> • Protective clothing and wildlife hazard warning, 1982.

Continued--

Table 9—EPA regulatory actions and special review status on major pesticides used in field crop production, 1972 - June 1993—Continued

Pesticide and concerns	Action of chemical	Regulatory action and date
Endrin • Carcinogenicity • Developmental toxicity • Reduction in endangered and nontarget species	Control cutworms in wheat and bollworms in cotton.	• All uses canceled, 1985.
EPN • Neurotoxicity • Hazard to aquatic organisms	Control corn borer, bollworm, boll weevil, tobacco budworm.	• All uses canceled, 1987.
Ethalfuralin • Carcinogenicity	Control annual grasses, pigweeds, and lambsquarter in peanuts and soybeans.	• Benefits exceeded risks, additional data required, 1985.
Heptachlor • Carcinogenicity	Control corn rootworm larvae, cutworms, and wireworms in corn.	• All uses canceled (except homeowner termite product), 1988.
Linuron • Carcinogenicity	Control broadleaf weeds and selected grasses in corn and soybeans.	• No regulatory action needed, 1989.
Monocrotophos • Avian effects	Control bollworms and budworms in cotton.	• All uses canceled, 1988.
Parathion • Acute human poisoning	Control armworms, aphids, cutworms, grasshoppers, and thrips in corn, cotton, potatoes, and wheat.	• Use for nine field crops only, 1991. • The use on nine crops are in pre-Special Review with additional toxicological data requested.
Terbutryn • Carcinogenicity • Mutagenicity • Reproductive effects	Control annual broadleaf and grass weeds in winter wheat in the Pacific Northwest.	• Label change to reduce applicator risk, 1982. List A, canceled.
Toxaphene • Carcinogenicity • Nontarget organisms • Acute toxicity to aquatic organisms • Chronic effects to wildlife	Control cotton insects, grasshoppers, armyworms.	• Most uses canceled (except emergency use for corn, cotton, and small grains for specific insect infestation), 1982.
Trifluralin • Carcinogenicity • Mutagenicity	Control annual grass and some broadleaf weeds in cotton and soybeans.	• Restrictions on product formulation, 1982.
Trillate • Carcinogenicity • Mutagenicity	Control wild oats in wheat and barley.	• Toxicity data required, 1984. • List B, in data waiting/review stage.
2,4-D [2,4-DB & 2,4-DP] • Carcinogenicity	Broadleaf weed control in small grains, corn, and soybeans. Lawn care by homeowners.	• In pre-Special Review. Proposed not to initiate Special Review, 1988. • An industry task force agreed to reduce exposure through label change and a user education program, 1992.
Methanearsonates [MSMA] • Carcinogenicity • Mutagenicity	Control annual grass and some broadleaf weeds in cotton.	• Insufficient evidence to initiate Special Review. • List B, in data waiting/review stage.

Source: USEPA, 1993.

primarily in the Pacific Northwest to control wireworms and nematodes. In 1992, it was applied at a rate of 4.6 pounds per acre. Esfenvalerate and permethrin, two synthetic pyrethroids, are not used in large quantities but they are important. Esfenvalerate was used on 20 to 30 percent of the fall potato acreage in the 1990-92 period while permethrin was used on 11 percent. Esfenvalerate is applied at 0.03 to 0.04 pound while permethrin is applied at 0.10 to 0.12 pound per treatment.

Mancozeb and maneb have been the two most heavily used fungicides currently and over time (table 8). Zineb was used extensively in 1966 but by 1971 its use had dropped dramatically and in the later surveys it was not reported. In the 1966 and 1971 surveys, mancozeb was not reported as a separate item but discussions with potato experts indicate that it was probably included in the "other" category. In 1979, maneb and mancozeb were reported together as one item. Chlorothalonil has been used since 1979.

Early and late blight are the two most serious diseases in fall potato production. Early blight kills the potato vine, reducing the food supply available for tuber production. Late blight kills the vine, and can also infect developed tubers, making them vulnerable to decay in storage.

Mancozeb, maneb, and chlorothalonil are protective fungicides in that they must kill the disease organism before it invades the foliage. Over time, fungicide use per treated acre has declined from 9.8 pounds in 1966 to the range of 3.0 to 4.0 pounds in the 1990's. In earlier times, growers often sprayed on a fixed schedule of an application every 7 to 10 days. In 1992, about 90 percent of the potato growers in Maine and the Pacific Northwest used pest management techniques to scout their fields for the presence of disease before making applications. This resulted in fewer but more timely and effective treatments.

Fertilizer Use on Major Field Crops by Crop and Plant Nutrient

Fertilizer use on major field crops is reported by plant nutrient (nitrogen, phosphate, and potash). Variations in nutrient use on a crop are due to combined effects of changes in planted acres, application rates, and the proportion of the planted acres fertilized. These pieces of information for four major field crops (corn, cotton, soybeans, and wheat) have been collected through the USDA's Objective Yield Survey annually since 1964. Crop-specific information reported in this section includes planted acres (fig. 7), total plant nutrient use (figures 8-10), application rates by plant

nutrient (figures 11-13), and percentage of acreage fertilized (figures 14-16). The numbers depicted in figures 7-16 are available from the authors.

Corn

Corn is the leading field crop in plant nutrient use, accounting for almost 9 million tons and 43.6 percent of total U.S. use (agricultural and nonagricultural) in 1992. Relative to other crops, the per-acre application rates for all three plant nutrients in corn production have been the highest. Also, over the past three decades, corn production has had the most planted acres. Therefore, corn is the leading user, by a substantial margin, in all three plant nutrient uses. In 1992, corn acreage received 4.9 million tons of nitrogen, 1.9 million tons of phosphate, and 2.3 million tons of potash; accounting for 67, 62, and 70 percent of nitrogen, phosphate, and potash, respectively, applied to the four major field crops.

Nitrogen use on corn rose sharply throughout the 1960's and 1970's due to higher application rates, greater percentage of acreage receiving nitrogen, and an increase in acreage. In 1964, 85 percent of corn acres were fertilized with nitrogen at a rate of 58 pounds per acre. The percentage of acreage fertilized with nitrogen increased to 96 percent and the application rate rose to 135 pounds per acre in 1979. During the 1980's and the early 1990's, the percentage of corn acreage fertilized with nitrogen has leveled off around 97 percent and the average application rate has fluctuated around 130 pounds per acre. Consequently, total nitrogen use on corn has been primarily influ-

Figure 7
Crop acreage planted, principal crops

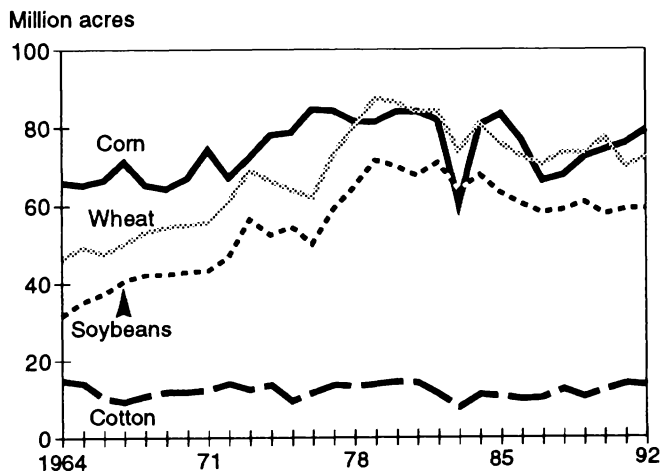


Figure 8

Estimated consumption of nitrogen, selected crops

Million nutrient tons

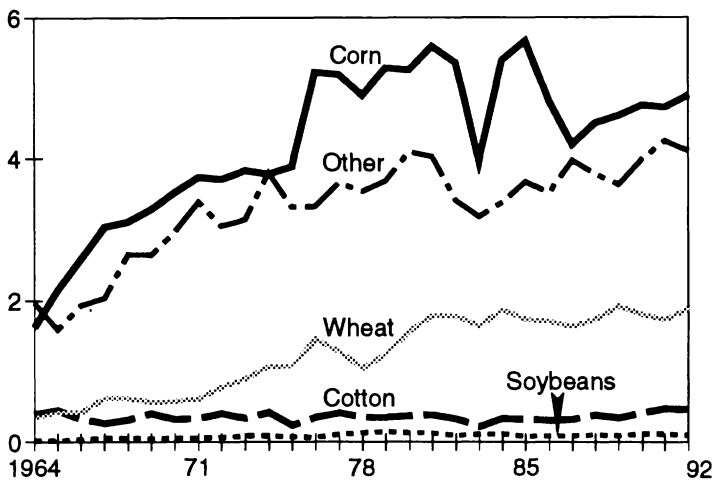
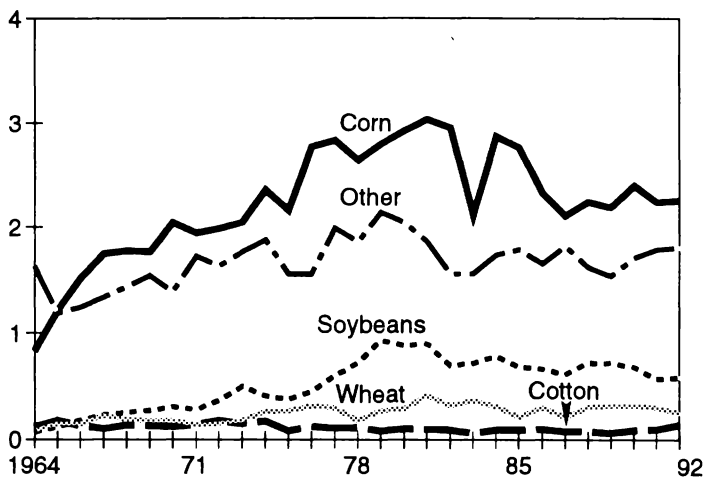


Figure 10

Estimated consumption of potash, selected crops

Million nutrient tons



enced by corn acreage since 1980. The 1983 Payment-In-Kind Program and the Acreage Retirement Program under the 1985 Farm Act greatly reduced the corn acreage and hence nitrogen use on corn.

The use of phosphate and potash on corn basically followed closely the general trend in nitrogen use, with some noticeable differences. Both the sharp increase in phosphate use during the 1960's and the dramatic increase in potash use in the 1960's and 1970's were caused by drastic increases in application rates, higher proportion of corn acreage treated, and increased acreage. The decline in phosphate application rates in the early 1970's was compensated by increased acreage,

Figure 9

Estimated consumption of phosphate, selected crops

Million nutrient tons

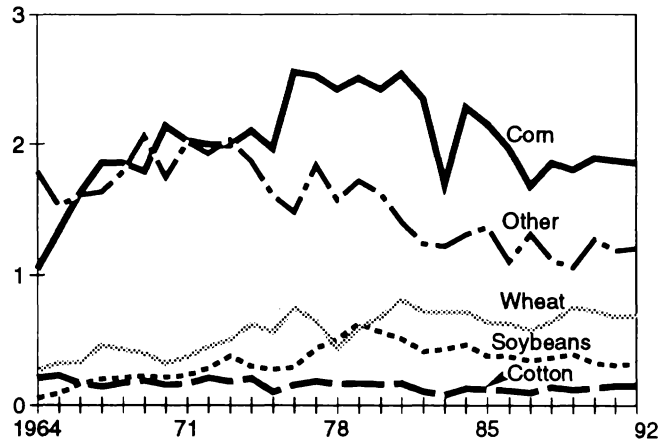
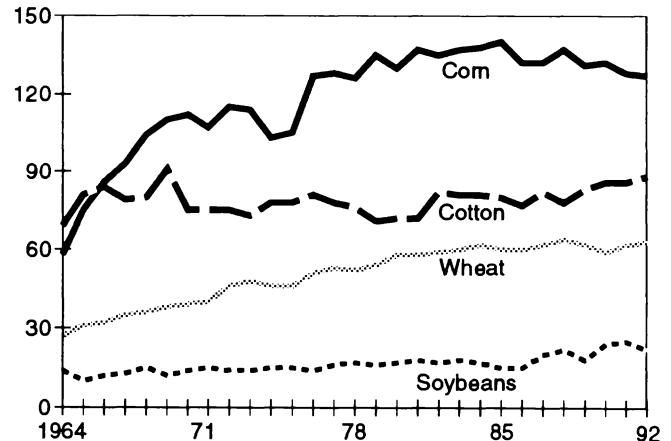


Figure 11

Nitrogen application rates, selected crops

Pounds per acre



with stable percentage of acreage fertilized, resulting in stable phosphate use on corn prior to 1976. Responding to favorable market conditions, the application rates for all nutrients rebounded and the corn acreage rose in 1976. Since 1980, the phosphate application rate has shown a moderate declining trend while the potash application rate has stabilized at around 85 pounds per acre. Furthermore, the percentage of corn acreage receiving phosphate and potash has declined while the percentage of corn acreage treated with nitrogen has been fairly stable since 1980. Similar to nitrogen use, phosphate and potash use on corn since 1980 has been primarily influenced by planted acres.

Figure 12
Phosphate application rates, selected crops

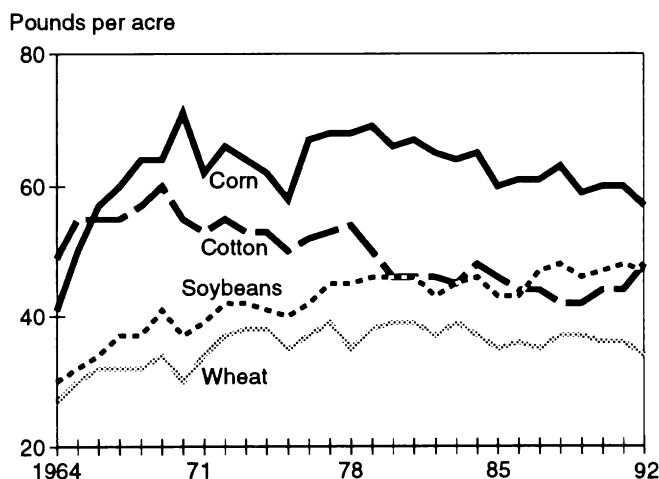


Figure 13
Potash application rates, selected crops

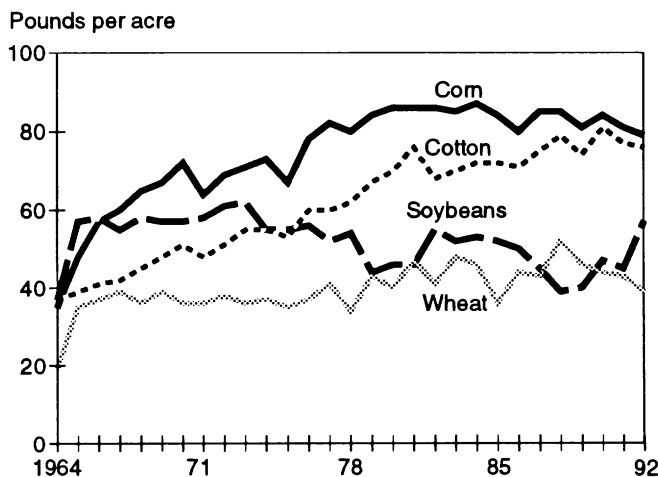


Figure 14
Percentage of acreage receiving nitrogen, selected crops

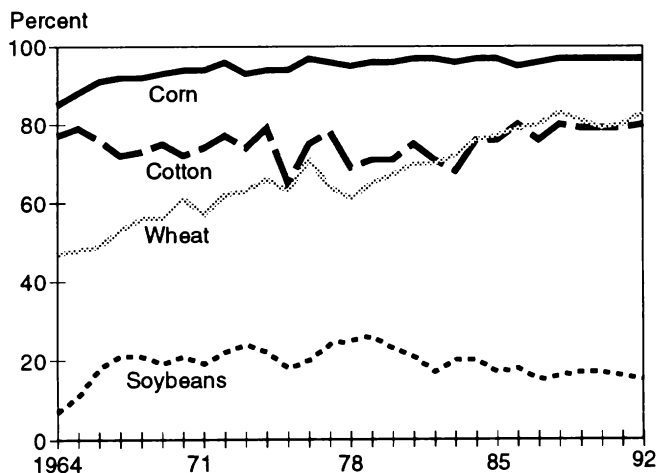
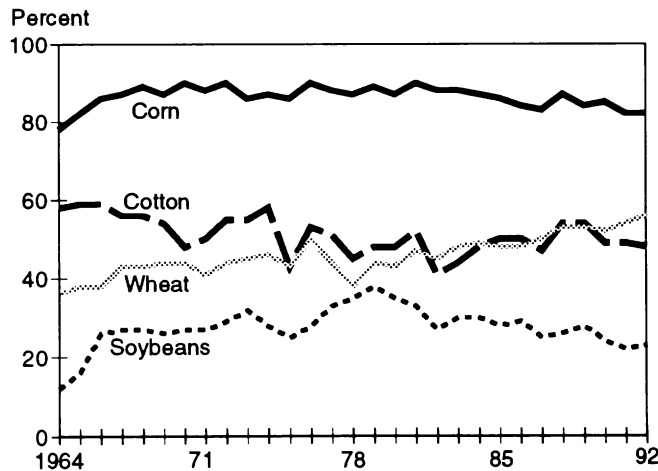


Figure 15
Percentage of acreage receiving phosphate, selected crops



Cotton

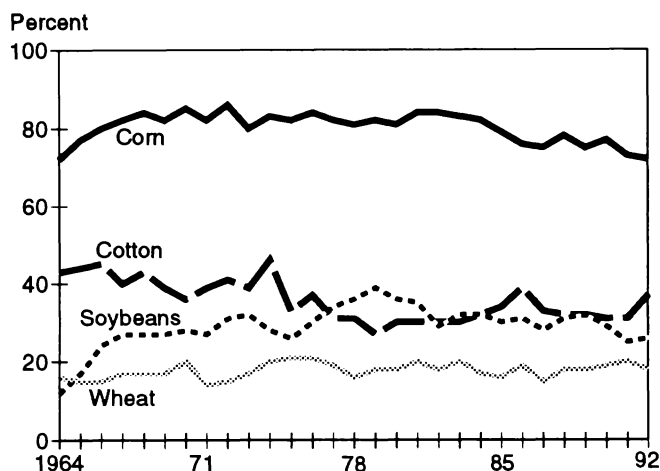
In 1964, cotton was the leading crop in terms of per-acre application rates with 69 pounds for nitrogen, 49 pounds for phosphate, and 37 pounds of potash. During that year, cotton was second only to corn in total nutrient consumption with a share of 7 percent, receiving 394,100 tons of nitrogen (9 percent of the U.S. total), 210,800 tons of phosphate (6 percent), and 118,000 tons of potash (4 percent). In 1992, cotton had only 4 percent share of U.S. nutrient consumption (4 percent of nitrogen, 4 percent of phosphate, and 3 percent of potash) mainly due to the small cotton acreage relative to other crops.

Cotton acreage, the percentage of cotton acres treated with nitrogen, and the nitrogen application rate all

fluctuated over the past three decades without any obvious trend. The share of cotton acreage receiving nitrogen ranged between 65 and 81 percent. The nitrogen application rates varied between 69 and 91 pounds per acre.

Unlike other field crops, the phosphate and potash application rates on cotton acres declined slightly over the past three decades; especially the phosphate application rate, which declined from 55 pounds in 1964 to 48 pounds in 1992. The percentage of cotton acreage treated with phosphate and potash also exhibited slight downward trends. Consequently, the amounts of phosphate and potash applied to cotton acres declined very slightly over time.

Figure 16
**Percentage of acreage receiving potash,
 selected crops**



Soybeans

During the 1964-79 period, soybeans' share of U.S. nutrient consumption increased from less than 1 to over 1 percent for nitrogen, from 2 to 11 percent for phosphate, and from 3 to 15 percent for potash. Consequently, soybeans' share of total U.S. nutrient consumption increased from 1 percent in 1964 to 8 percent in 1979.

These dramatic increases were due to the combined effects of an increase in the proportion of soybean acreage fertilized, increases in application rate, and a 125-percent increase in acreage. These combined effects are results of favorable market conditions and high loan rates in the late 1970's. Soybean planted acres increased from 32 million acres in 1964 to the record high of 71 million acres in 1979. The proportions of soybean acreage treated with nitrogen, phosphate, and potash all increased from their lowest levels in 1964 to their highest levels in 1979; from 7 to 26 percent for nitrogen, from 12 to 38 percent for phosphate, and from 12 to 39 percent for potash. The nitrogen application rate was quite stable at around 14 pounds per acre prior to 1977 and then rose to over 16 pounds per acre during the 1977-86 period. The phosphate and potash application rates have also trended upward, starting with 30 pounds of phosphate and 37 pounds of potash per acre in 1964 and reaching 46 pounds of phosphate and 67 pounds of potash in 1979.

Since 1979, the percentage of soybean acreage fertilized trended downward for all three plant nutrients; declining to 15 percent for nitrogen, 23 percent for

phosphate, and 26 percent for potash in 1992. Application rates for nitrogen and phosphate showed very minor increases while the potash application rate continued to increase. Meanwhile, soybean planted acreage started to decline and totaled 59 million acres in 1992. Consequently, soybeans' share of total U.S. nutrient consumption declined to 1 percent for nitrogen, 8 percent for phosphate, and 12 percent for potash in 1992.

Wheat

Over the past three decades, wheat's share of total U.S. nutrient consumption increased considerably. Wheat production accounted for 8, 8, and 3 percent of total nitrogen, phosphate, and potash consumption, respectively, in 1964, and these shares increased to 17, 16, and 5 percent in 1992. Wheat planted acreage increased from less than 56 million acres in 1964 to the record high of 88 million acres in 1981, and then declined to 72 million acres in 1992.

Increases in nitrogen consumption in wheat production have been substantial, rising from 353,000 nutrient tons in 1964 to almost 1.9 million nutrient tons in 1992. This rapid increase in nitrogen use was mainly due to the combined effects of an increase in the percentage of acreage treated with nitrogen (from 47 to 83 percent between 1964 and 1992) and high application rates (from 27 to 63 pounds per acre). The percentage of wheat acreage treated with phosphate and the phosphate application rate have also increased over time, although not as dramatically as nitrogen use. Both the percentage of wheat acreage fertilized with potash and the potash application rate showed very minor increases over the past three decades. Consequently, phosphate and potash consumption in wheat production was more closely related to changes in wheat acreage.

Factors Influencing Agricultural Chemical Use

Farmers use an array of fertilizer and pest management practices, resulting in a diverse pattern of agricultural chemical use. Additionally, agricultural chemical use is known to be influenced by other factors, including government programs and weather. Extensive research has been conducted to analyze the effects of some production practices and government programs on agricultural chemical use. Because previous studies rarely utilize farm-level data on a national or regional scale, it is useful to test the validity of the findings reported in the literature using

national or regional farm-level data. Identification of less chemical-intensive production practices is an important step toward reducing agricultural chemical use.

As discussed earlier, data on agricultural chemical use and related information have been collected through various USDA surveys. Specifically, the Cropping Practices Surveys (CPS) provide a multi-year data base for validating the findings that exist in the literature. A literature review was conducted to summarize the major findings. The review is focused on the areas that can be examined using the CPS data for corn production collected during the 1990-92 period. Then, the empirical results of a regression analysis are highlighted to validate previous findings and to identify less chemical-intensive production practices. The CPS corn data were chosen as a case study because corn acreage accounted for over half of herbicides and over a quarter of insecticides applied to the crops discussed in the section on pesticide use trend (table 2).

Literature

The literature review focuses on four factors that influence agricultural chemical use: tillage systems, rotations, application timing and methods, and commodity programs. It is well known that integrated pest management practices (IPM), such as scouting and use of economic thresholds, influence agricultural chemical use. Even though recent USDA chemical use surveys have collected IPM information, the data were not available for this analysis. A comprehensive review of IPM literature was recently completed (Norton and Mullen).

Tillage Systems

Over the past three decades, farmers have adopted several distinct tillage practices to prepare their fields for planting. Over time, tillage systems have been defined in a number of ways and have different meanings to members of the agricultural community, making it difficult to develop historical trends in tillage practices (Dickey and others; Duffy and Hanthorn). The delineation of tillage practices can be thought of as a continuum based on the amount of plant residue left on the field and the extent of soil disturbance. No-till and conventional-till (especially with the use of the moldboard plow) comprise the extremes of the continuum.

Conventional-till involves extensive field preparation prior to planting, incorporating 70 percent or more of the plant residue into the soil. The use of the moldboard plow in conventional-till almost eliminates plant residue, making it useful to classify conven-

tional-till into two practices—conventional-till with and without the moldboard plow.

Conservation tillage includes those systems (no-till, ridge-till, and mulch-till) that leave 30 or more percent of the plant residue on the soil surface after planting. No-till is a practice by which plant residue is left virtually undisturbed on the field surface. Planting is completed in a narrow seedbed or slot created by the planter or drill. Ridge-till is a system where the soil is left undisturbed from harvest to planting. At planting, the ridges are cleared of plant residue for seedbed preparation, but plant residue is left undisturbed in the row middles. Mulch-till encompasses all other systems where the soil is disturbed prior to planting but meets the criteria of more than 30 percent residue cover after planting. Detailed definitions of various tillage systems can be found in Bull.

Adoption of conservation-till in major field crops, such as corn and soybeans, increased in the early 1980's as farmers attempted to save labor, fuel, and machinery costs and to achieve higher profits. Still, conventional-till has remained the predominant tillage practice in corn and soybean production. Reasons cited for farmers' reluctance to adopt conservation tillage practices prior to 1980 were fear of reduced yields, greater weed problems, capital investment in machinery, and reluctance to change practices (Duffy and Hanthorn).

Since 1985, conservation tillage practices have increased steadily. Between 1987 and 1992, on corn acreage, conventional-till with the moldboard plow declined from 21 to 12 percent, conventional-till without the moldboard plow dropped from 60 to 49 percent, mulch-till increased from 14 to 25 percent, and no-/ridge-till rose from 5 to 14 percent (USDA/ERS, 1993 and 1986). Between 1988 and 1992, on soybean acreage, conventional-till with the moldboard plow decreased from 22 to 10 percent, conventional-till without the moldboard plow declined from 63 to 53 percent, mulch-till increased from 12 to 22 percent, and no-/ridge-till rose from 4 to 15 percent. These increases in the adoption of conservation tillage are mainly caused by the conservation compliance provisions of the 1985 and 1990 Farm Acts, which require farmers to implement conservation plans on highly erodible land (HEL) by 1995 or lose program benefits. Currently, some 148 million acres of cropland have been determined to be HEL, of which 141 million acres have approved USDA conservation plans. The plans include crop residue management as part of the recommended treatment on about 75 percent of the 110 million HEL acres planted to crops.

The effects of conservation tillage on input use, crop yields, and economic returns have not been conclusively determined. The empirical evidence on the relative profitability and risk of different tillage is mixed (Fox and others). A common view is that conservation tillage requires more nitrogen fertilizer than conventional tillage because cooler and more moist soils slow the mineralization of nitrogen and promote denitrification (Crosson). Fewer tillage operations and mechanical cultivations for weed control with conservation tillage may require additional herbicide use. More herbicides, insecticides, and fungicides may be required with conservation tillage because the additional plant residue provides an environment for pest development and ties up a portion of the pesticide material applied.

The above views have not been supported in some empirical studies. In an analysis of field-level data for corn and soybean production in 1980, Duffy and Hantorn reported substantial evidence to refute the common view that conservation tillage systems require more chemical use than conventional tillage systems. Consequently, Logan and others conclude that the perceived greater use of nitrogen and pesticides with conservation tillage appears to be unfounded. Recent USDA survey data also cast doubts on the validity of the perceived greater use of chemical input with conservation tillage (Bull and others). Obviously, agricultural chemical use is influenced by an array of factors, and some of them (such as cropping patterns, application timing and methods, government programs, etc.) may have greater impacts than tillage systems.

Crop Rotations

Crop rotations involve planting different crops successively in the same field. Compared with continuous cropping, crop rotations provide two types of benefits related to chemical use. Crop rotations maintain soil moisture and fertility, and thus reduce farm-level demand for fertilizer. It has been shown that rotations can increase grain crop yields beyond those achieved with continuous cropping under similar conditions (Power; Cook, 1984; Goldstein and Young; Heichel; Pimentel and others; Voss and Shrader).

Another major benefit of crop rotations is the control of insects, diseases, and weeds—particularly insects and diseases that attack the plant roots (Cook, 1986). Rotating crops to control insects has a long history and was one of the most important methods of insect control before insecticides came into general use (Sailer). During the early 1940's, little or no insecticides were applied to corn, and losses to insects were

small. Since then, insecticide use in corn production has increased dramatically, mainly due to increased continuous cropping. Rotating corn with another crop, such as soybeans, can significantly reduce the amount of insecticides needed for treating corn rootworm larvae, a major corn insect. Among the 60.4 million corn acres in the 17 major producing States in 1991, 24 percent were in 3-year corn, 12 percent were in 2-year corn, 46 percent were in the corn and soybean sequence, and the remaining 18 percent had other crops (mainly fallow, alfalfa, wheat, and oats) as the previous crop (USDA/ERS, Oct. 1992).

Crop rotations can be effective in interrupting the development of the disease and weed life cycle (Marshall; Slife). Rotating crops is possibly the oldest and most widely practiced diversification strategy used in agricultural production for disease control (Curl). Plant pathogens usually have narrow host ranges and will not survive in the absence of the host. For example, crop rotations are known to reduce many diseases in wheat and tobacco production (Roberts).

Weeds having the same life cycle as the crop tend to increase rapidly when the crop is grown continuously. For example, in continuous corn, summer annual weeds, both grasses and broadleaves, would tend to dominate. When corn is followed by winter wheat, the intensities of the summer annual weeds decrease because winter wheat competes with weeds in the early spring, thus reducing germination and their further establishment (Slife). While some weed control can be accomplished by crop rotations, weed control usually is not a primary purpose of crop rotations (Zimdahl).

Application Timing and Methods

Timing and method of application greatly influence the amount of agricultural chemicals applied and thus have important agronomic, economic, and environmental ramifications. Many experimental plot studies have been conducted by plant and weed scientists to examine the effects of timing and method of chemical applications on nutrient uptake by plants, weed control, and yields. However, little analysis has been done with farm-level data.

Pre-plant applications of nitrogen are relatively inefficient because of denitrification, leaching, and run-off, whereas late-applied (sidedressed) nitrogen is used more effectively by plants (Feinerman and others). In an experimental plot study, it was shown that the corn yield achievable with 160 pounds of fall-applied nitrogen could also be obtained with only 80 pounds of sidedressed nitrogen (Lathwell and others). However,

price incentives, resource limitations, and the potential for a wet spring often encourage farmers to apply some nitrogen in the fall. Consequently, split nitrogen applications provide farmers with more flexibility than the strategy of a single application either before planting or in late spring (Ogg, 1978). In 1992, about 28 million acres of corn in the 17 major producing States (or 39 percent of planted acres) received a single, pre-plant nitrogen application; 32 million acres (or 49 percent of planted acres) received split nitrogen applications before, at, or after seeding; 3 percent of acres were not treated with nitrogen; and the remaining 9 percent were treated exclusively either at or after seeding.

Soil-applied, preemergence herbicides have been the foundation of row crop weed control for the past 30 years (Kapusta). In 1992, about 41 and 64 percent of corn and soybean planted acres, respectively, received pre-plant herbicides. (Herbicides applied before planting are usually, but not necessarily, preemergence herbicides.) Compared with preemergence herbicides, postemergence herbicides have little or no soil residual activity and are applied only when needed (after scouting and using economic thresholds). There is a trend toward more use of postemergence herbicides, which is expected to accelerate in the future for two reasons (Kapusta). First, the introduction of new postemergence herbicides and the sharp decrease in cost of several older postemergence herbicides increase the use of postemergence herbicides. Second, conservation tillage has increased and will continue to increase, limiting the option of incorporating pre-emergence herbicides into the soil.

Farmers are expected to adopt newly developed practices of integrated pest management (IPM) in weed control. With IPM, farmers determine the need for treatment and select the herbicide after the weed problem has been identified. The IPM weed strategy has been augmented in recent years by research data on weed threshold levels, and the development of computer software programs to aid farmers in evaluating various weed control strategies. However, there are limitations to total postemergence programs. Greater attention must be paid to management details, such as close monitoring of weather conditions and weed development. While postemergence herbicides provide good control of annual weeds when they are small, they may not be effective in controlling large weeds. Because rain may prevent timely applications of post-emergence herbicides, total postemergence programs are considered more risky than preemergence programs.

Fertilizers and pesticides are generally applied as either banded or broadcast treatments. The best method of fertilizer application depends on many factors, including soil fertility and tillage system (Doane Information Service). Application rates per treated area do not vary between broadcast and banded applications. However, broadcast applications cover the entire surface area while banded applications generally cover only one-third of the surface area. While banded applications save materials, the broadcast applications save labor and time because the weeds in the row middles are also controlled, reducing the need for mechanical cultivation. Farmers may choose to broadcast fertilizer in order to build up soil fertility or because of economic reasons; broadcast saves labor and time at planting and allows application of bulk materials that may be lower priced.

Commodity Programs

The literature is replete with analyses of the effects of commodity programs on chemical use. The majority of research findings suggest that commodity programs have increased chemical use in agricultural production (Shoemaker and others; Hertel and others; Ogg, 1990; Young and Painter; Goldstein and Young; NAS, 1989). However, the findings were not supported in some studies (Gargiulo; Heady and Yet). As stated by Mjelde and others, "Input intensity differences between program participants and non-participants is a complicated issue." Indeed, farm programs may influence agricultural chemical use through several channels (Miranowski; Ogg, 1990; Young and Painter), as discussed below.

First, farm programs raise prices and reduce price variations in program crops. Higher prices mean higher marginal revenues for inputs, and hence motivate additional input use. For risk-averse farmers, the price guarantee provided by target prices or loan rates may encourage additional nonland input use.

Second, deficiency payments are tied to the base acreage and program yields. Base acreage (before 1990) and program yields (before 1985) were computed by means of a 5-year moving average. The need to maintain base acreage for program crops induced inflexibility in cropping patterns (Daberkow and Reichelderfer). The cross-compliance provision of the Food Security Act of 1985 served as an effective financial barrier to diversification into other program crops, for which farmers do not have base acres. The inflexible cropping patterns created by farm programs are dominated by major program crops (U.S. House of Representatives; Ek). Because some program crops (mainly corn) use more chemicals than nonprogram

crops (with the exception of fruits and vegetables), the base acreage requirement has contributed to increased chemical use. The 1990 Farm Act permits farmers the flexibility to plant 15 to 25 percent of their base acreage to other programs or specified other crops without losing future base acreage, hence providing some flexibility in cropping patterns. Before 1985, documentation of higher yields contributed directly to increased program payments in future years. Therefore, farmers might have applied additional non-land inputs to increase future program benefits. Currently, program yields have been frozen at the 1981-85 level so the incentive for increasing yields to gain future program benefits has been removed.

Third, farm programs may affect agricultural chemical use through the Acreage Reduction Program (ARP). When an ARP is announced, farmers have to set aside a certain percentage of the base acreage in order to be eligible for loans and deficiency payments. An ARP may increase or decrease agricultural chemical use. Because few chemicals are applied to set-aside acres, a reduction in total cropped area may reduce total agricultural chemical use. Further, cover crops can be planted on set-aside land as green manure and hence reduce fertilizer needs the following year. Also, surplus fixed factors (for example, equipment and management) can substitute for agricultural chemical inputs in the short run (Carlson and others). For example, mechanical cultivation can substitute for herbicides and the use of economic thresholds may improve the efficiency of pesticide use. However, if the quality of land in a farm is heterogeneous, then farmers may actually idle poor-quality land. This slippage may affect per-acre agricultural chemical use in two ways: agricultural chemical use (for example, fertilizers) increases with land quality; and ARP reduces total supply of the program crop, and bids up the price and marginal return of the program crop.

Empirical Results of a Case Study on Corn Production

The influence of production practices and government programs on agricultural chemical use is a complex issue, and contradicting views and research findings exist in the literature. Further, results of experimental plot studies may not prevail in actual farm operations. In order to more accurately identify and quantify the factors that influence agricultural chemical use, we conduct a regression analysis utilizing cross-sectional, field-level production data. The CPS corn data are chosen as a case study because corn acreage accounted for 57 percent of herbicides and 28 percent of insecticides used on the crops discussed in the section on pesticide use trend (table 2).

Data

The CPS survey for corn covers 17 major producing States during the 1990-92 period. A subset of the data (9,287 observations) was used in the analysis; specifically, nonirrigated corn production for grain in 10 States (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, South Dakota, Wisconsin, and Kentucky) was included in the analysis, representing 66 percent of U.S. grain corn production.

Nitrogen, herbicides, and insecticides are the major agricultural chemicals used in corn production and analyzed in this study. Nitrogen use was measured in terms of pounds per acre, while two measures of herbicide and insecticide inputs were used: total pounds or total cost per acre of active ingredients applied. Many pesticide active ingredients are used in corn production and their prices and efficacy vary widely.

Among the corn acreage included in the analysis, nitrogen, herbicides, and insecticides were applied to 99, 99, and 26 percent of the acres, respectively. Application rates per treated acre were 129, 3.19, and 1.03 pounds of nitrogen, herbicides, and insecticides, respectively. Treatment costs (excluding application cost) per treated acre were \$18.44 and \$11.42 for herbicides and insecticides, respectively.

On average, the 10 States represented approximately 48 million acres of grain corn production annually during the 1990-92 period. Four tillage practices were commonly practiced, including two conventional tillage practices (conventional-till with and without the moldboard plow, representing 16 and 56 percent of the corn acreage, respectively) and two conservation tillage practices (no-till and mulch-till, accounting for 10 and 19 percent of the corn acreage, respectively). Four cropping sequences were developed according to the previous crops planted, including 3-year corn (18 percent of the corn acreage), 2-year corn (12 percent), corn/soybean (soybeans followed by the surveyed corn with 56 percent), and corn/other (another crop other than corn or soybeans followed by the surveyed corn with 14 percent). With respect to timing and method of applications, farmers were distinguished by whether they relied exclusively on pre-plant applications and whether they completely banded chemicals. Approximately 49, 27, and 5 percent of the corn acreage received only pre-plant nitrogen, herbicides, and insecticides, respectively. Pre-plant applications were hypothesized to use more nitrogen and pesticides than at/after planting applications. Broadcast applications use more chemicals than banded applications. Among treated acreage, approximately 6, 10, and 80 percent

of the acres received only banded applications of nitrogen, herbicides, and insecticides, respectively.

When both participation in the feedgrain program and cropping sequences are found to influence chemical use, interactive variables are used to determine whether program effects vary across cropping sequences, and vice versa. The literature suggests that the commodity programs have induced inflexibility in cropping sequences. Given the degree of inflexibility in cropping sequences (that is, the probability of switching from a diversified cropping pattern to continuous corn under program), the regression results can be used to estimate the direct effect of commodity programs on chemical use as well as the "indirect" effect channelled through changes in cropping sequences. The influence of commodity programs on cropping sequences was not investigated in this study. Therefore, the program effect was only partially analyzed since only the direct effect is estimated.

The sample selection procedure, regression estimation procedure, and empirical results are fully documented in Lin and others. In the remainder of this section, the major empirical findings are highlighted.

Did Tillage Systems Affect Nitrogen and Pesticide Use?

The empirical results suggest that farmers who practiced conservation tillage (mulch-till and no-till) used similar amounts of nitrogen as farmers who practiced conventional-till with or without the moldboard plow. These findings are consistent with the results reported by Duffy and Hanthorn, and do not support the view that reduced tillage tends to require more nitrogen.

Conventional-till with the moldboard plow was found to receive fewer pounds of herbicides and incur lower herbicide costs than the other three tillage practices, other things being equal. Conventional-till without the moldboard plow, no-till, and mulch-till used a similar amount of herbicides, but no-till incurred higher herbicide costs than the other two tillage practices. Therefore, a switch from conventional tillage to conservation tillage does not necessarily increase herbicide use. The above findings are independent of the effects of mechanical cultivation on herbicide use (the effect of mechanical cultivation is discussed later). Similarly, a switch from conventional tillage to conservation tillage may or may not increase insecticide use, depending on the cropping sequences which were found to be the predominant determinant of insecticide use.

Did Crop Rotations Affect Nitrogen and Pesticide Use?

Farmers who planted 3-year corn used more nitrogen than farmers who planted corn following a crop other than corn. However, farmers who grew corn for only 2 consecutive years did not significantly use more nitrogen than farmers who planted corn following soybeans. Even though soybeans are known to provide rotational benefit in terms of nutrient requirement, many farmers did not appear to give credit to the residual nitrogen. Also, cropping patterns were found to have limited effects on weed control, supporting the view that weed control is not a primary objective of crop rotations.

Rootworm larvae is the predominant insect problem facing corn farmers, and the problem intensifies when corn is planted continuously. Therefore, crop diversity greatly reduces insecticide use. Rotating corn with another crop provides effective rootworm control. The share of acreage treated with insecticides in the corn/soybean sequence was found to be 8 percent, compared with 61 and 48 percent for the 3-year and the 2-year corn sequence, respectively. Among treated acreage, the corn/soybean sequence also used less insecticides (significant at the 5-percent level): 0.11 pound and \$1.36 per acre less than the 3-year corn and 0.06 pound and \$0.98 per acre less than the 2-year corn. Switching from 3-year to 2-year corn also reduced the percentage of acreage treated with insecticide by 15 to 33 percent and lowered the application rate by 0.05 pound per treated acre.

Did Commodity Programs Increase Nitrogen and Pesticide Use?

As stated earlier, this analysis examined only the direct effect of commodity programs on chemical use. Commodity programs might have altered cropping sequences and hence indirectly affected chemical use. The empirical results suggest that participation in the feedgrain program was not associated with higher nitrogen use during the 1990-92 period. However, participation in the feedgrain program was associated with higher herbicide use and costs among fields in the 2-year corn and the corn/soybean sequence. Further, program participation was also found to increase the percentage of acreage treated with insecticides, but not the application rates, among fields in continuous corn. Therefore, the empirical results of this study provide some support to the view that commodity programs contribute to greater chemical use in corn production.

The indirect effect of commodity programs on chemical use can possibly outweigh the direct effect. Because a small percentage of soybean acreage is treated with nitrogen and low rates are applied to treated acreage, the corn/soybean sequence receives much less nitrogen than continuous corn over a 2-year period. If commodity programs have increased the number of years of corn in crop rotations, then we can conclude that commodity programs have contributed to the greater use of nitrogen, herbicides, and insecticides. However, Gargiulo provides empirical evidence showing that commodity programs actually increase crop diversity and thus reduce insecticide use in corn production. Obviously, future research is warranted to improve our understanding of farmers' rotation decisions in order to appraise the overall effect of commodity programs on agricultural chemical use.

Can Nitrogen and Pesticide Use Be Reduced by Altering Timing and Method of Applications?

The empirical results indicate that pre-plant application rates used over 4 pounds of nitrogen per acre more than other application timings, and the broadcast method used 57 pounds per acre more than the band method. Similarly, farmers who completed herbicide applications before planting used more herbicides, 0.28 pound per acre, but incurred \$1.76 lower cost per acre than other farmers. Most of the herbicides applied before planting are less expensive because they usually are older materials with expired patents. Alachlor, atrazine, and metolachlor, the three most widely used herbicides on corn, are prime examples. Farmers who banded herbicides used 0.61 pound less and incurred \$3.14 per acre less in cost than farmers who broadcast herbicides.

Contrary to the findings on herbicide use, pre-plant applications did not use more insecticides than other timings, and banded applications used more insecticides than broadcast applications. Higher use associated with banded applications can be explained by the fact that rootworm larvae is the predominant insect problem in corn production, which is usually controlled by banded applications. Farmers who broadcast insecticides to treat cutworms, European corn borers, and mites used insecticides which are applied at lower rates.

Other Practices for Reducing Chemical Use on Corn

Some farmers substituted manure for chemical fertilizers. The empirical results suggest that the manure-

treated fields received an average of 13 pounds less nitrogen per acre than other fields. Mechanical cultivation for weed control can substitute for herbicides. Each cultivation was found to reduce herbicide use by nearly 0.17 pound and costs by \$0.65 per acre. However, after factoring in the costs of mechanical cultivation and herbicide applications, herbicides appear to be more cost effective than mechanical cultivation in controlling weeds. Approximately 21 percent of the no-till acres were cultivated while 70 percent of other tillage acres were cultivated. Among the cultivated acres, the number of cultivations did not vary significantly among the four tillage practices. Therefore, a switch from conventional- and mulch-till to no-till is likely to thwart mechanical cultivation and hence increase herbicide use.

Highlights

Pesticide Use Trends

- Pesticide use on the selected crops more than doubled during 1964-82 (from 233 to 612 million pounds), as cropland acreage increased, the proportion of acres treated with pesticides rose, and application rates per treated acre went up. Since 1982, agricultural pesticide use has trended slightly downward, mainly due to the decline in cropland acreage. Total pesticide use amounted to 533-564 million pounds in 1990-92.
- During the 1960's, agricultural pesticide use was dominated by insecticides, accounting for about half of all pesticides used. Since 1976, insecticide use has declined by more than half and accounted for 10 percent of total agricultural pesticide use in recent years. The decrease in insecticide use came mainly from cotton production, where organochlorines (DDT and toxaphene) were banned and replaced by pyrethroids.
- During 1964-82, agricultural herbicide use increased more than eightfold, accounting for much of the increase in pesticide use during the period. In 1982, herbicides accounted for over three-fourths of total pesticides. Since 1982, herbicide use declined due to shrinking crop acreage, and accounted for about 70 percent of total pesticides in 1990-92.
- Fungicides and other pesticides (soil fumigants, growth regulators, and harvest aids) accounted for about one-fifth of total pesticides in recent years. Fungicides are commonly used on vegetables and fruits and soil fumigants are commonly used on vegetable crops.

- Total quantity of pesticides used on a crop is determined by the percentage of acres treated, the application rate per treated acre, and the planted acres. Corn leads other crops, by a substantial margin, in pesticide use. In 1992, 79 million acres of cropland were planted with corn (32 percent of crop acres), which received 245 million pounds of pesticides (43 percent of total pesticides). Wheat occupies the second largest acreage (29 percent), but accounted for less than 4 percent of total pesticides. Soybeans accounted for 59 million acres (one-fourth of crop acres) and received 68 million pounds of pesticides (12 percent of total pesticides). Cotton, with 13 million planted acres and nearly 58 million pounds of pesticides applied in 1992, accounted for 5 percent of crop acres and nearly 10 percent of total pesticides.
- Among the major crops, rice is the most intensive user of herbicides, on a per-acre basis. Peanuts require intensive fungicide treatments, accounting for 20 percent of total fungicide use in 1992. Vegetables, including potatoes, represented less than 2 percent of crop acreage in 1992, but received 17 percent (98 million pounds) of total pesticides. Vegetables accounted for 13 percent of insecticides, 49 percent of fungicides, and 79 percent of other pesticides used in 1992. Citrus and apples accounted for less than 1 percent of total acres but received 4 percent of total pesticides. The 8 million pounds of fungicides applied to citrus and apples in 1992 accounted for 25 percent of total fungicides.

Fertilizer Use Trends

- U.S. nitrogen, phosphate, and potash use for all purposes (agricultural and nonagricultural) rose from 7.5 million nutrient tons in 1960 to a record high of 23.7 million tons in 1981. Total nutrient use has dropped to 20.7 million tons in 1992 because of the decline in total crop acreage.
- Nitrogen, phosphate, and potash all shared in the dramatic increase in fertilizer use up to 1981. The relative use of nitrogen, however, increased much more rapidly. Nitrogen use in 1960 was about 37 percent of total nutrient use. By 1981, nitrogen use reached its record high of 11.9 million tons, and represented over 50 percent of total fertilizer use. This relative gain in nitrogen use has resulted primarily from favorable crop yield responses to nitrogenous fertilizers, especially corn. Phosphate's share of total nutrient consumption declined steadily from 34 percent in 1960 to 21 percent in 1992. Potash consumption, historically below that of both nitrogen and

phosphate, exceeded phosphate consumption for the first time in 1977 with a share of 26 percent of the total and reached its record high level of 6.3 million tons in 1981. Use of potash has fallen since 1981, and in 1992 it accounted for 24 percent (5 million pounds) of total fertilizer use.

- Data on annual use of nutrients are available for corn, cotton, soybeans, and wheat since 1964. U.S. farmers use more fertilizer on corn than on any other crop. Between 1964 and the mid-1980's, fertilizer use on corn increased with larger acreage, higher application rates, and increased proportion of acres treated. Corn acres received 3.5 million tons of fertilizers (34 percent of all use) in 1964 and 10.6 million tons (49 percent) in 1985. Since 1985, fertilizers used on corn acres declined with smaller acreage, amounting to almost 9 million pounds in 1992.
- Among the four field crops surveyed, cotton has the smallest share of total U.S. nutrient consumption and has the smallest acreage. In 1992, 778,000 tons (4 percent of total) of nutrients were used on 13 million acres of cotton. In 1964, however, cotton had the highest per-acre application rate and was second only to corn in total nutrient consumption with an estimated 723,000 tons, or 7 percent of the total.
- Nutrient use on soybeans increased rapidly from 1964 (143,000 tons and 1 percent of the total) to the record high (1.7 million tons and 8 percent of the total) in 1979. These increases were due to the combined effects of an increase in the proportion of acreage fertilized, increased application rates, and a 125-percent increase in acreage. Since 1979, nutrient use on soybeans has trended downward and by 1992 stood at 1 million tons. Wheat, the second most important crop with respect to nutrient use, received 2.8 million tons (14 percent of the total) in 1992. This is a considerable increase from the 708,000 tons consumed in 1964 when wheat ranked third in total tonnage behind corn and cotton. Nitrogen consumption on wheat has risen the most over this period as total use of nitrogen increased by over 400 percent, while the acreage was up by 30 percent from 1964. This rapid increase in nitrogen use is a result of increased application rates that have more than doubled and an increase in the proportion of wheat acres fertilized.

Factors Influencing Chemical Use on Corn

- Similar per-acre rates of nitrogen were applied to corn acreage under conservation and conventional tillage systems. A switch from conventional tillage with the moldboard plow to other tillage systems (conventional without the moldboard plow, mulch-till, and no-till) tends to increase herbicide use. Similar amounts of herbicides are applied to corn acreage, on a per-acre basis, under conventional tillage without the moldboard plow, mulch-till, and no-till if the same level of mechanical cultivation is employed. Compared with other tillage systems, no-till tends to employ a lower level of mechanical cultivation for weed control.
- Crop rotation is effective in reducing the use of insecticides on corn acreage, but has limited effect on herbicide use. Even though legume crops are known to provide benefits in terms of nutrient availability, many farmers did not appear to give credit to the residual nitrogen.
- Participation in commodity programs was found to contribute to greater herbicide and insecticide use on certain corn acreage, but it did not increase nitrogen use. This study does not investigate whether commodity programs alter cropping sequencing and hence chemical use on corn acreage.
- Application timing and method were found to greatly influence nitrogen and herbicide use on corn. Switching from pre-planting to after-planting applications and from broadcast to band applications can reduce nitrogen use by 4 and 57 pounds per acre, respectively. Similarly, banding/after-planting reduced herbicide use as compared with broadcasting/pre-planting. However, most herbicides applied before planting are less expensive because they are older materials with expired patents.

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Appendix A: USDA Agricultural Chemical Use Surveys

Since 1964, USDA has conducted numerous surveys to collect detailed information on the use of commercial fertilizers and pesticides in agricultural production. The USDA's Objective Yield Surveys, beginning in 1964, provided annual estimates of primary nutrients applied to corn, cotton, soybeans, and wheat. Periodic surveys were conducted to collect pesticide data on treated acreage and quantities applied to agricultural crops. The earlier pesticide surveys provided estimates for all crops, while later surveys focused on selected commodities and production areas.

Between 1964 and 1982, five national pesticide surveys were conducted (1964, 1966, 1971, 1976, and 1982; appendix tables 1 and 2). The first three surveys obtained total farm use of pesticides and provided regional estimates of acreage, quantities, and expenditures for all crop and livestock uses. The 1976 and 1982 surveys continued the collection of whole farm pesticide use, excluding livestock, fruits, vegetables, and minor crops and some States, but still represented about 85 percent of U.S. cropland. Regional estimates were provided for percentage of acreage treated and quantities used. These five earlier national surveys were costly because of national coverage, and were burdensome to respondents to provide information for all their pesticide use. Such comprehensive surveys were replaced with crop- and State-specific, but more detailed surveys in recent years.

Crop-specific surveys were conducted during the 1977-80 period for citrus (1977), deciduous fruits (1978), upland cotton (1979), vegetables (1979), fall

potatoes (1979), grapes (1979), corn, soybeans, and sorghum (1982). These surveys offered more reliable data on each pesticide active ingredient (a.i.) applied to the crop, and some of them also provided nutrient and pest management information.

Since 1986, the Cropping Practices Surveys (CPS) for corn, upland cotton, soybeans, and wheat have collected information on both commercial fertilizer and pesticide use. These surveys cover the major producing States of each crop as well as the States where chemical use has caused concerns about water quality and other environmental risks. Fall potatoes and rice were added to the CPS in 1988. The pesticide information obtained between 1986 and 1989 included acres treated with individual pesticide products, but no information on quantities applied. Since 1990, both acres treated and per-acre application rates by active ingredient have been collected. Data on pest management practices have also been collected, starting with surveys of corn, soybean, and fall potato production in 1993.

The USDA's Pesticide Data Program (PDP), funded under the 1989 President's Food Safety Initiative, has an objective of improving the pesticide data base by establishing pesticide residue monitoring activities and by expanding pesticide use surveys (USDA/AMS, 1992). Fruits and vegetables are the primary target of the PDP, with alternate surveys to cover most vegetables in one year (starting in 1990) and fruits the following year (starting in 1991). The 1990 vegetable survey was limited to four States and the 1991 fruit survey excluded California.⁷ The surveys conducted in 1992 (vegetables) and 1993 (fruits and nuts) covered most U.S. production, and collected data on chemical input use and pest management practices.

Appendix figure 1 illustrates the geographic scope and intensity of the 1992 USDA chemical use surveys. These surveys are designed to provide individual active ingredient, treated acreage, and application rate estimates reliable at the State level. To provide such estimates, large sample sizes are required. For example, in 1992, nearly 15,000 personal interviews in 32 States were conducted to develop nutrient and pesticide use estimates.

Appendix B: Development of Pesticide Use Estimates

This appendix documents the assumptions and calculations used to develop comparable pesticide use estimates over time. Earlier USDA pesticide use sur-

veys covered all pesticide use in agriculture, but surveys conducted after 1971 have only partially represented all agricultural uses. Because the later surveys did not represent a common set of commodities and States, their total use estimates are not comparable between years. Comparable estimates are developed to show changes in pesticide use since 1964.

These estimates are developed for 8 benchmark years: 1964, 1966, 1971, 1976, 1982, 1990, 1991, and 1992. Total quantities of herbicides, insecticides, fungicides, and other pesticides are estimated for upland cotton, corn, rice, sorghum, soybeans, wheat, peanuts, potatoes, other vegetables, citrus fruits, and apples. These crops currently account for about 250 million acres or 72 percent of U.S. cropland used for crops. The earlier surveys in 1964, 1966, and 1971 reported that these crops accounted for 79 to 85 percent of all pesticides used in agriculture.

Methodology

The general procedure for developing the estimates was to first calculate application rates per planted acre by crop from the survey data, then multiply those rates by their respective acreage. This procedure assumes the percentage of acreage receiving treatments and the pesticide application rates on the survey acreage is representative of the total acreage of that crop. Most surveys represented over 80 percent of the U.S. acreage. For some benchmark years, survey data were missing for some crops and estimates had to be developed to provide consistent coverage.

Appendix tables 1-4 document the information used to develop estimates shown in table 2. Appendix table 1 lists the commodity acreage represented in each of the USDA pesticide use surveys from 1964 to 1992. When a commodity was not surveyed in a particular year, the acreage for that year is not reported in appendix table 1. Appendix table 2 shows the estimated quantity of herbicide, insecticide, fungicide, and other pesticides reported from the USDA pesticide use surveys (1 - 14). Dividing the pesticide quantities by planted acres leads to application rates per planted acre (appendix table 3). By multiplying the application rates with their respective U.S. acreage (appendix table 4) we develop the pesticide use estimates for the 8 benchmark years (table 2).

⁷In California, agricultural pesticide use has to be recorded with the county commissioner's office. To reduce the respondent's burden, an effort was made to obtain California pesticide use data through the mandatory records. The incorporation of California data in the 1991 fruit survey data encountered the problem of data incompatibility. This problem was resolved for the 1992 vegetable survey.

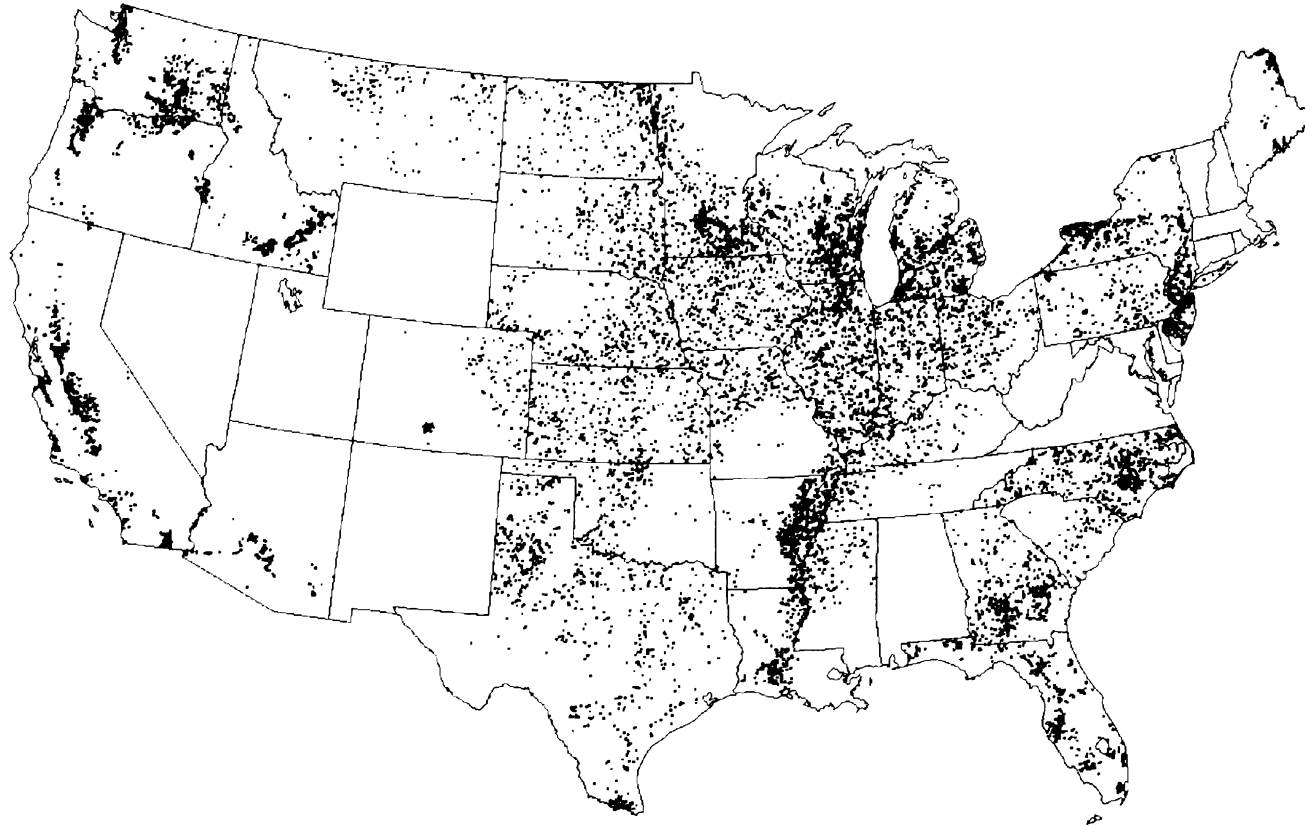
Because not all crops were surveyed for the 8 benchmark years and some pesticide uses were aggregated among crops, several of the application rates reported in appendix table 3 had to be constructed. For missing values in 1964, the 1966 rates were assumed with the exception of potatoes, other vegetables, citrus, and apples (discussed later). For missing values in 1976, rates were calculated by interpolating between the 1971 value and the next available value (1977, 1978 or 1979). For missing values in 1982, rates were calculated by interpolating between the 1977-79 rates and the 1991-92 rates. The peanut and sorghum rates for 1990 assume the 1991 rates. Missing values for other vegetables, citrus, and apples in 1991 are the interpolated rates between 1977-79 rates and 1991-92 rates. For missing values in 1992, the 1991 rates were assumed.

In 1964, herbicides applied to potatoes, other vegetables, citrus, apples, other fruits, and nuts were

reported as a single value. In 1966, herbicide use on these crops was reported separately. The first step in developing individual 1964 herbicide rates per acre for these crops was to calculate the aggregate per acre rates for 1964 and 1966. The 1966 rates were then adjusted by the ratio of the aggregate 1964 rate to the 1966 rate to obtain an estimate of the 1964 rate for individual crops. The calculation is detailed in appendix table 5.

In 1966, other pesticides applied to potatoes and other vegetables were reported as a single value. Individual per-acre rates for 1964 were adjusted using the procedure described above to estimate 1966 rates per acre. Also, in 1971, other pesticides applied to potatoes and other vegetables were reported as a single value. Individual per-acre rates for 1979 were adjusted to obtain estimates of 1971 rates per acre. Appendix table 5 shows these calculations.

Appendix figure 1
Chemical use survey coverage, 1992



Each point on the map represents one of the approximately 22,000 personal interviews conducted in 1992 to obtain chemical use data on corn, cotton, potatoes, rice, soybeans, vegetables, and wheat.

Appendix table 1—ERS pesticide use surveys, commodity acreage represented, 1964-92

Commodities	1964 ¹	1966 ¹	1971 ¹	1976 ²	1977 ²	1978 ²	1979 ²	1982 ²	1990 ²	1991 ²	1992 ²
1,000 acres											
Corn	65,823	66,347	74,179	84,374				81,857	74,171	68,580	71,375
Cotton	14,836	10,349	12,355	11,656				10,000	9,825	10,850	10,115
Wheat	55,672	54,105	53,822	80,202				79,800	58,950	50,530	55,890
Sorghum	16,770	16,372	20,547	18,402				16,028		8,050	
Rice	1,797	1,980	1,826	2,489				3,295	1,795	1,860	2,030
Soybeans	31,721	37,294	43,476	50,226				67,543	57,795	53,230	53,050
Peanuts	1,487	1,490	1,529	1,549				1,311		1,492	
Potatoes	1,311	1,498	1,432				1,012		1,100	1,131	1,068
Other vegetables	3,274	3,471	3,168				1,926		821		2,978
Citrus ³	781	890	1,194		1,180					591	
Apples ³	451	421	402			383				350	
Other deciduous ^{3,4}	683	666	610			224				387	
Other fruits and nuts ³	1,003	1,025	1,087								
Other cropland	139,391	136,092	124,373	91,902							
Total	335,000	332,000	340,000	340,800				259,834	204,456	197,051	196,506

¹Survey was designed to represent all crop and livestock uses.

²Surveys were limited to selected crops and major production areas.

³Acres obtained from "Fruits and Nuts, Bearing Acreage, 1947-83", SB-761, USDA, NASS, 1987, and recent updates to the series.

⁴Represents apricots, cherries, grapes, nectarines, peaches, pears, plums, and prunes. Calculated by subtracting apple acres from the NASS acres of major deciduous fruit.

Sources: USDA, ERS. *Quantities of Pesticides Used by Farmers, 1964*. AER-131, Jan. 1968; USDA, ERS. *Quantities of Pesticides Used by Farmers in 1966*, AER-179, Apr. 1970; USDA, ERS. *Farmers' Use of Pesticides in 1971-Quantities*. AER-252, July 1974; Eichers, T., P. Andrienas, and T. Anderson, *Farmers' Use of Pesticides in 1976*. AER-418, USDA, ERS, Dec. 1978; Haydu, J. *Pesticide Use in U.S. Citrus Production, 1977*, Staff Report No. AGES80203, USDA, ERS, Feb. 1981; Webb, S. *Preliminary Data: Pesticide Use on Selected Deciduous Fruits in the United States*, Staff Report No. AGES810626, USDA, ERS, July 1981; Parks, J. *Pesticide Use on Fall Potatoes in the United States, 1979*, Staff Report No. AGES830113, USDA, ERS, Jan. 1983; Ferguson, W. *Pesticide Use on Vegetables in Five Regions, 1979*, Staff Report No. AGES 83-920, USDA, ERS, Jan. 1984; USDA, ERS. *1982 Pesticide Use Survey*, ERS electronic data product; USDA, ERS. *1990 Cropping Practices Survey*, ERS electronic data product; USDA, ERS. *1991 Cropping Practices Survey*, ERS electronic data product; USDA, ERS. *1992 Cropping Practices Survey*, ERS electronic data product; USDA, NASS. *Agricultural Chemical Usage: 1993 Fruits Summary*. Ag Ch 1 (94), 1994b; USDA, NASS. *Agricultural Chemical Usage: 1992 Vegetables Summary*. Ag Ch 1 (93), 1993b; USDA, NASS. *Agricultural Chemical Usage: 1991 Fruit and Nuts Summary*. Ag Ch 1 (92), 1992b; USDA, NASS. *Agricultural Chemical Usage: 1990 Vegetables Summary*. Ag Ch 1 (91), 1991b.

Appendix table 2—ERS survey estimates of total quantity of pesticide applied

Commodities	1964	1966	1971	1976	1977	1978	1979	1982	1990	1991	1992
<i>1,000 pounds of herbicides</i>											
Corn	25,476	45,970	101,060	207,061				243,409	217,500	189,800	201,913
Cotton	4,628	6,526	19,610	18,312				18,288	16,800	20,100	19,690
Wheat	9,178	8,247	11,622	21,879				18,068	12,700	9,800	13,456
Sorghum	1,966	4,031	11,538	15,719				15,738		10,300	
Rice	¹	2,819	7,985	8,507				14,089	10,000	10,400	11,298
Soybeans	4,208	10,409	36,519	81,063				126,960	74,400	62,900	60,381
Peanuts	¹	2,899	4,374	3,366				4,929		3,300	
Potatoes	5,846	2,220	2,178				1,107		1,855	2,046	1,716
Other vegetables	²	3,488	3,361				4,000		2,094		4,981
Citrus	²	353	676		5,515					4,223	
Apples	²	389	197			706				309	
Other deciduous	²	³	³			142				478	
Other fruits and nuts	²	2,856	1,503							5,010	
Other crops	30,858	22,213	25,037	17,971				14,124			
Total herbicides	76,314	112,420	225,660	373,878				455,605	335,349	318,666	313,435
<i>1,000 pounds of insecticides</i>											
Corn	15,668	23,629	25,531	31,979				30,102	23,200	20,800	18,778
Cotton	78,022	64,900	73,357	64,139				16,924		6,300	11,694
Wheat	¹	876	1,712	7,236				2,640	740	150	892
Sorghum	¹	767	5,729	4,604				2,559		767	
Rice	¹	312	946	508				565	100	200	114
Soybeans	4,997	3,217	5,621	7,866				11,073	nr	400	322
Peanuts	¹	5,529	5,993	2,439				1,035		1,400	
Potatoes	1,456	2,972	2,770				3,058		2,821	2,889	2,802
Other vegetables	8,290	8,163	8,268				4,200		2,727		4,668
Citrus	1,425	2,858	3,049		5,537					2,764	
Apples	10,828	8,494	4,831			2,964				2,890	
Other deciduous	³	³	³			1,161				1,402	
Other fruits and nuts	4,476	6,619	6,274							10,190	
Other crops	18,022	9,230	10,175	11,527				6,334			
Total insecticides	143,184	137,566	154,256	130,298	5,537	4,125	7,258	71,232	29,588	50,152	39,270

See notes at end of table

Continued--

Appendix table 2—ERS survey estimates of total quantity of pesticide applied—Continued

Commodities	1964	1966	1971	1976	1977	1978	1979	1982	1990	1991	1992
<i>1,000 pounds of fungicides</i>											
Corn	1	1	1	20				69	nr	nr	nr
Cotton	171	376	220	49				176		541	600
Wheat	1	1	1	862				1,007	131	53	893
Sorghum	1	1	1	nr				nr		nr	
Rice	1	1	1	nr				80	120	275	248
Soybeans	1	1	1	176				68	nr	nr	76
Peanuts	1	1,108	4,431	6,834				4,740		5,937	
Potatoes	3,229	3,531	4,124				3,544		2,206	2,548	2,883
Vegetables	4,530	4,093	5,666				4,800		5,336		14,696
Citrus	4,929	4,056	9,257		5,141					2,501	
Apples	7,750	8,496	7,207			5,884				3,272	
Other deciduous	2,621	1,804	3,822			1,324				9,264	
Other fruits and nuts	1,417	2,498	3,096							14,735	
Other crops	6,068	4,528	1,732	154				455			
Total fungicides	30,715	30,490	39,555	8,095	5,141	7,208	8,344	6,595	7,793	39,126	19,396
<i>1,000 pounds of other pesticides</i>											
Corn	76	546	443	483				130	nr	nr	nr
Cotton	12,431	14,207	18,696	12,682				8,239		11,935	12,056
Wheat	1	47	245	nr				nr	nr	nr	nr
Sorghum	1	40	1	266				44		nr	
Rice	1	1	1	nr				17	nr	nr	70
Soybeans	1	49	52	2,030				2,315	nr	nr	nr
Peanuts	1	7,005	471	1,188				1,627		1,917	
Potatoes	91	4	4				6,714			36,650	39,607
Other vegetables	5,819	5,910	10,435				3,100		17,635		20,596
Citrus	1,539	681	1,280		nr					10	
Apples	1,037	1,079	548			555				nr	
Other deciduous	3	3	3			76				71	
Other fruits and nuts	1,041	2,918	1,772							81	
Other crops	19,162	8,423	12,317	18,526				11,945			
Total other pesticides	41,196	40,905	46,259	35,175				12,372	17,635	50,664	72,329

See notes at end of table

Continued

Appendix table 2—ERS survey estimates of total quantity of pesticide applied—Continued

Commodities	1964	1966	1971	1976	1977	1978	1979	1982	1990	1991	1992
<i>1,000 pounds of all pesticides</i>											
Corn	41,220	70,145	127,034	239,543				273,710	240,700	210,600	220,691
Cotton	95,252	86,009	111,883	95,182				43,627	16,800	38,876	44,040
Wheat	9,178	9,170	13,579	29,977				21,715	13,571	10,003	15,241
Sorghum	1,966	4,838	17,267	20,589				18,341		11,067	
Rice	¹	3,131	8,931	9,015				14,751	10,220	10,875	11,730
Soybeans	9,205	13,675	42,192	91,135				140,416	74,400	63,300	60,779
Peanuts	¹	16,541	15,269	13,827				12,331		12,554	
Potatoes	4,776	8,723	9,072				14,423		6,882	44,133	47,008
Other vegetables	18,639	21,654	27,730				16,100		27,792		44,941
Citrus	7,893	7,948	14,262		16,193					9,499	
Apples	19,615	18,458	12,783			10,109				6,471	
Other deciduous	2,621	1,804	3,822			2,703				11,215	
Fruits and nuts	6,934	14,891	12,645							30,016	
Other crops	74,110	44,394	49,261	48,178				32,858			
Total pesticides	291,409	321,381	465,730	547,446	10,678	11,333	15,602	545,804	390,365	458,608	444,430

nr = none reported.

¹Included in other crops.²In 1964, potatoes, other vegetables, fruits, and nuts were reported as one value.³Included in other fruits and nuts.⁴Included in other vegetables.

Sources: See the references in appendix table 1.

Appendix table 3—Application rates per planted crop acre¹

Commodities	1964	1966	1971	1976	1977	1978	1979	1982	1990	1991	1992
<i>Pounds of herbicide per planted acre</i>											
Corn	0.387	0.693	1.362	2.454				2.974	2.932	2.768	2.829
Cotton	0.312	0.631	1.587	1.571				1.829	1.710	1.853	1.947
Wheat	0.165	0.152	0.216	0.273				0.226	0.215	0.194	0.241
Sorghum	0.117	0.246	0.562	0.854				0.982	1.280 ³	1.280	1.280 ³
Rice	1.424 ²	1.424	4.373	3.418				4.276	5.571	5.591	5.566
Soybeans	0.133	0.279	0.840	1.614				1.880	1.287	1.182	1.138
Peanuts	1.946 ²	1.946	2.861	2.173				3.759	2.212 ³	2.212	2.212 ³
Potatoes	0.989 ⁴	1.482	1.521	1.254 ⁵			1.094	1.256 ⁶	1.687	1.810	1.607
Other vegetables	0.670 ⁴	1.005	1.061	1.696 ⁵			2.077	1.984 ⁶	1.735 ⁶	1.704 ⁶	1.673
Citrus	0.265 ⁴	0.397	0.457	3.970 ⁵	4.673			5.556 ⁶	6.635 ⁶	7.145	7.145 ³
Apples	0.617 ⁴	0.924	0.389	1.427 ⁵		1.843		1.548 ⁶	0.815 ⁶	0.883	0.883 ³
<i>Pounds of insecticide per planted acre</i>											
Corn	0.238	0.356	0.344	0.379				0.368	0.313	0.303	0.263
Cotton	5.259	6.271	5.937	5.503				1.692	1.100	0.581	1.156
Wheat	0.016 ²	0.016	0.032	0.090				0.033	0.013	0.003	0.016
Sorghum	0.047 ²	0.047	0.279	0.250				0.160	0.103 ³	0.103	0.103 ³
Rice	0.158 ²	0.158	0.518	0.204				0.171	0.056	0.108	0.056
Soybeans	0.158	0.086	0.129	0.157				0.164	0.000	0.008	0.006
Peanuts	3.711 ²	3.711	3.920	1.575				0.789	0.938 ³	0.938	0.938 ³
Potatoes	1.111	1.984	1.934	2.318 ⁵			3.022	2.898 ⁶	2.566	2.555	2.624
Other vegetables	2.532	2.352	2.610	1.775 ⁵			2.181	2.039 ⁶	1.662 ⁶	1.615 ⁶	1.567
Citrus	1.825	3.213	2.554	3.843 ⁵	4.692			4.687 ⁶	4.678 ⁶	4.677	4.677 ³
Apples	23.993	20.185	12.011	8.960 ⁵		7.739		7.898 ⁶	8.220 ⁶	8.257	8.257 ³

See notes at end of table.

Continued--

Appendix table 3—Application rates per planted crop acre¹—Continued

Commodities	1964	1966	1971	1976	1977	1978	1979	1982	1990	1991	1992
<i>Pounds of fungicide per planted acre</i>											
Com	0.000	0.000	0.000	0.000				0.001	0.000	0.000	0.000
Cotton	0.012	0.036	0.018	0.004				0.018	0.080	0.050	0.059
Wheat	0.000	0.000	0.000	0.011				0.013	0.002	0.001	0.016
Sorghum	0.000	0.000	0.000	0.000				0.000	0.000 ³	0.000	0.000 ³
Rice	0.000	0.000	0.000	0.000				0.024	0.067	0.148	0.122
Soybeans	0.000	0.000	0.000	0.004				0.001	0.000	0.000	0.001
Peanuts	0.744 ²	0.744	2.898	4.412				3.614	3.979 ³	3.979	3.979 ³
Potatoes	2.463	2.357	2.880	2.962 ⁵			3.502	3.094 ⁶	2.006	2.254	2.700
Other vegetables	1.384	1.179	1.789	1.581 ⁵			2.492	3.056 ⁶	4.559 ⁶	4.747 ⁶	4.935
Citrus	6.314	4.559	7.754	4.922 ⁵	4.356			4.312 ⁶	3.950 ⁶	4.232	4.232 ³
Apples	17.173	20.190	17.919	16.093 ⁵		15.363		13.512 ⁶	9.778 ⁶	9.349	9.349 ³
<i>Pounds of other pesticide per planted acre</i>											
Com	0.001	0.008	0.006	0.006				0.002	0.000	0.000	0.000
Cotton	0.838	1.373	1.513	1.088				0.824	1.230	1.100	1.192
Wheat	0.000	0.001	0.005	0.000				0.000	0.000	0.000	0.000
Sorghum	0.000	0.002	0.000	0.014				0.003	0.000 ³	0.000	0.000 ³
Rice	0.000	0.000	0.000	0.000				0.005	0.000	0.000	0.034
Soybeans	0.000	0.001	0.001	0.040				0.034	0.000	0.000	0.000
Peanuts	4.701 ²	4.701	0.308	0.767				1.241	1.285 ³	1.285	1.300 ³
Potatoes	0.069	0.006 ⁴	4.467 ⁴	6.095 ⁵			6.634	11.658 ⁶	25.055	32.416	37.096
Other vegetables	1.777	0.164 ⁴	1.084	1.584 ⁵			1.610	2.834 ⁶	6.100 ⁶	6.508 ⁶	6.916
Citrus	1.971	0.766	1.072	0.179 ⁵	0.000			0.006 ⁶	0.016 ⁶	0.017	0.017 ³
Apples	2.298	2.564	1.363	1.424 ⁵		1.449		1.003 ⁶	0.104 ⁶	0.000	0.000 ³

¹Rates were developed by dividing total quantity in appendix table 2 by represented acres in appendix table 1.²Assumed the 1966 rate.³Assumed the 1991 rate.⁴Only aggregate values were reported.⁵Values were calculated by interpolating between 1971 and 1977, 1978, or 1979. See app. table 5 for construction of values for specific crops.⁶Values were calculated by interpolating between 1977, 1978, or 1979 and 1990, 1991 or 1992.

Appendix table 4--Planted crop acres, 1964-92

Commodities	1964	1966	1971	1976	1982	1990	1991	1992
<i>1,000 planted acres</i>								
Corn	65,823	66,347	74,179	84,374	81,857	74,171	75,951	79,325
Cotton	14,836	10,349	12,355	11,656	11,345	12,348	14,052	13,290
Wheat	55,672	54,105	53,822	80,202	86,232	77,241	69,921	72,262
Sorghum	16,770	16,372	20,547	18,402	16,028	10,535	11,064	13,277
Rice	1,797	1,980	1,826	2,489	3,295	2,897	2,878	3,174
Soybeans	31,721	37,294	43,476	50,226	70,884	57,795	59,180	59,330
Peanuts	1,487	1,490	1,529	1,549	1,311	1,840	2,039	1,690
Potatoes	1,311	1,498	1,432	1,407	1,303	1,400	1,408	1,339
Other vegetables	3,274	3,471	3,168	3,195	2,190	2,670	2,639	3,280
Citrus ¹	781	890	1,194	1,198	1,132	850	886	945
Apples ¹	451	421	402	403	419	473	465	472
Area represented	193,923	194,216	213,930	255,101	275,997	242,220	240,483	248,385

¹Johnson and Doyle. *Fruits and Nuts, Bearing Acreage, 1947-83*, USDA, NASS, SB-761, 1987.

Sources: USDA, Agricultural Statistics, 1979 (for 1964-61), 1992 (for 1976-1992).

Appendix table 5—Calculations of some rate estimates in appendix table 3

	1966 quantity	1966 acres	1966 rate	1964 quantity	1964 acres	1964 rate
Herbicides:¹						
Potatoes	2,220	1,498	1.482			0.989
Other vegetables	3,488	3,471	1.005			0.671
Citrus	353	890	0.397			0.265
Apples	389	421	0.924			0.617
Other fruits and nuts	2,856	1,691	1.689			1.127
Total	9,306	7,971	1.167	5,846	7,503	0.779
Other pesticides:²						
Potatoes			0.006	91	1,311	0.069
Other vegetables			0.164	5,819	3,274	1.777
Total	591	4,969	0.119	5,910	4,585	1.289
	1979 quantity	1979 acres	1979 rate	1971 quantity	1971 acres	1971 rate
Other pesticides:³						
Potatoes	6,714	1,012	6.634			4.467
Other vegetables	3,100	1,926	1.610			1.084
Total	9,814	2,938	3.340	10,345	4,600	2.249

¹Herbicides: The 1964 rate = 0.779 divided by 1.167 times individual 1966 crop rates.

²Other pesticides: The 1966 rate = 0.119 divided by 1.289 times individual 1964 crop rates.

³Other pesticides: The 1971 rate = 2.249 divided by 3.340 times individual 1979 crop rates.